PROCEEDINGS

# SIXTEENTH ASIAN-PACIFIC WEED SCIENCE SOCIETY CONFERENCE

*'INTEGRATED WEED MANAGEMENT TOWARDS SUSTAINABLE AGRICULTURE'*

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# SIXTEENTH ASIAN-PACIFIC WEED SCIENCE SOCIETY CONFERENCE

*Editor*

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# PREFACE

I take this opportunity to thank the President and Board Members of the APWSS for their support and encouragement to the organisers of the 16$^{th}$ Conference of APWSS in Kuala Lumpur. A special word of thanks to Dr. Anwar A. Ismail, Chairman of the Main Organising Committee, for his relentless support and guidance in ensuring the successful and timely publication of the conference papers.

This publication is a compilation of the conference papers and is presented in a standard journal format. In the process of editing, every effort has been made to retain the original meaning and views of the authors. All claims on commercial products and processes and views expressed does not necessarily imply endorsement by the editors or the Malaysian Plant Protection Society.

This publication we believe, will serve as a useful source of information and achieve its primary objective of disseminating new information and experiences to academics, researchers, specialists, farm managers and students in weed science. Keywords and author index have been included to facilitate easy reference by the user.

The organisation of an international gathering of experts of this nature, including planning and coordination of technical sessions and compilation of this publication, could not have been achieved without the combined effort of all members of the main organising committee and the relevant sub-committees. Contributions by all members, in particular the members of the editorial committee and convenors of sessions are hereby gratefully acknowledged.

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# SUSTAINABLE WEED MANAGEMENT - FACT OR FALLACY?

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*Summary*: The management of weeds has been an incessant struggle in the history of humankind. The evolution of weeds resistant to herbicides has caused concern about our ability to devise effective and profitable systems of weed management that will keep weeds at low levels for long periods, not damage the environment and release people from laborious tasks. Weeds invade most habitats, adapt to environmental disturbances and circumvent our attempts to control them. We have little knowledge about the ecology of invasiveness and adaptability of most weeds. Consequently, we must continue to devise systems of quarantine and management in the presence of this ignorance. Weed management systems (WMS) will be more sustainable if they integrate a range of methods to avoid and control weeds. The methods for WMS will consist of diverse and persistent attacks on weeds to circumvent their adaptive mechanisms and keep them at low levels. Strengths in weed science and technology exist in areas of: education and research; extension; regulation; private, government and society infrastructures for research and development; farm practice and management. Threats to progress in WMS include: levels and emphasis of funding for research and development; concerns for the environment; a lack of a systems approach in education and research. Productivity of the land must be increased and sophisticated technology will be needed. The wise use of technology and resources needs to be assessed by societies with legitimate concerns about the quality of the environment and their well-being in open and productive structures for the resolution of conflicts. An appendix describes a systems approach to WMS through detailed consideration of six recursive steps in the development and implementation of WMS. Computer simulation describes resilience under disturbance, and the need for sustained development and adoption of new technology through investment in education and research.

*Keywords*: weed ecology, computer simulation.

## INTRODUCTION

"Can we devise sustainable weed management systems?" This question captures our concerns about the threat of weeds to the use of land and water resources and, as a consequence, to the quality of our lives. The damage from weeds is insidious, relentless and costly. The science and technology of weed control has made great advances over the last 50 years. However, despite modern technology, we face defeat in the war against weeds (1, 11, 14). These failures to keep weeds under control have been due to our inability to match the increased magnitude and complexity of the task with sufficient will and effort. We need advantages from technology to overcome this mis-match. Yet technology has failed us because we have used it improperly (11), or we have yet to allocate sufficient resources to invent effective technology and have it adopted. The struggle against weeds is dynamic because they are resilient and adaptable to systems of land-use. It is unwise, therefore, to expect any specific system of weed management to suit all situations and to remain effective indefinitely. We should, however, seek general principles to guide us in the development of WMS and for these to be adapted to local situations (2, 16, 17).

Current hopes for a reversal in the war against weeds emphasise the integration of a number of options for weed control into systems of management aimed at long-term management rather than short-term control. The objective of these integrated systems is long-term sustainability in resource-use and pest management with reductions in the use of pesticides (9, 24). This paper reviews current strengths and challenges in weed science and technology, and the threats to the development of more sustainable WMS. Details of a systems-approach to WMS are provided and some needs are identified for changes in the way we think about weed-management, and priorities for research and education.

## CO-EVOLUTION OF WEED-MANAGEMENT AND HUMANKIND

Weeds have interfered with human activities since recorded time. As our activities have become more diverse and complex so too have our weed problems. In the evolution of modern agriculture it has become necessary to develop methods to nourish and protect domesticated plants and animals. The methods of management in modern systems of agriculture have been driven by the need to employ less labour and increase productivity. People who have been released from manual systems of agriculture have pursued other occupations and accelerated the cultural development of modern societies. In return, these cultural developments have benefited agriculture through the development and adoption of innovations (pest and weed management - including pesticides; plant breeding; chemical fertilisers; mechanisation; irrigation; etc).

The co-evolution of human societies and agriculture (Fig. 1) is on-going and has reached different levels of sophistication around the world. However, low technology farming systems should not follow the same paths to modernisation as those of current high technology systems. Rather, within their own culture, they have the opportunity to adapt modern systems (17) and avoid the mistakes of the early adopters (11).

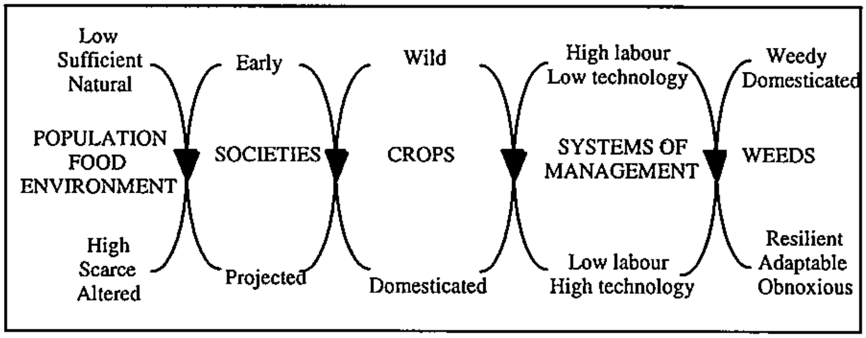



Fig. 1. The on-going, co-evolution of agriculture and society (after Harlan 1976). High technology systems of management protect domesticated species from resilient and adaptable weeds and release people from laborious tasks. Sustainable systems of management will require continued innovation and adoption of technology so that scarce and often degraded resources can be used to produce our increasing and changing needs for primary products– yet improve and conserve the quality of the environment.

## FARMING SYSTEMS OF SOUTHERN AUSTRALIA: THE PURSUIT OF SUSTAINABILITY

Over the last 25 years there has been a change in the way land is managed in the farming systems of southern Australia. The climate is a cool, wet winter and a hot, dry summer. The stable farming system was wheat in rotation with annual, self-regenerating pastures grazed by sheep. The pastures were legumes and many annual grass and broad-leaf weeds. The pasture species were the weeds of the wheat and were controlled by grazing, cultivations prior to sowing the crop, and selective post-emergence herbicides for some broad-leaf weeds (2,4-D; MCPA). This 'clover-ley' farming system was considered sustainable and showed gradual improvements in productivity – although soils were prone to erosion. Changes to this farming system were necessary because of persistent increases in costs of production relative to prices for wheat and, particularly, wool and sheep-meat. Change to more profitable systems was made possible through technology innovation. Crops could be established with minimum tillage because of herbicide technology (paraquat; diquat; glyphosate; diphenylethers; aryloxyphenoxypropionates; cyclohexanediones; thiocarbamates; triazines; substituted ureas). New pulses (particularly *Lupinus angustifolius* on acid, sandy soils) could be rotated with cereals in continuous cropping systems. New cultivars of crops were developed to exploit the intensive cropping systems made possible by herbicide technology. These new farming systems of intensified cropping were considered sustainable until the development of herbicide resistance of a number of weeds to several herbicides. Present trends in research to new sustainable farming systems are aimed at the management of the seed banks of the annual weeds by reversion to grazed pastures in less intensive, and less profitable, cropping systems. Herbicides will feature in the new cropping systems, including transgenic resistance in crops to the non-selective herbicides, but their use will benefit from the recognition of the adaptability of weeds to selection pressures. Weed research has been, predominantly, for the development of recommendations for herbicides and undertaken by 'part-timers' (those with duties other than weeds research) with insecure funding (6). The threat to sustainable agriculture from herbicide resistant weeds has changed attitudes towards the needs for weeds research (19) although research-management seeks short-term, applied goals – the quick-fix (25).

## SUSTAINABILITY

If "sustainable" means to continue indefinitely our present activities and lifestyles then many farmers in the world would consider their present farming systems as unsustainable (1). They would prefer to escape from the manual burden of food production (such as hand-weeding) through the adoption of modern technology (Fig. 1) – if they could afford to do so. Fortunate farmers who enjoy relative wealth and leisure, through adoption of technology, would hope their lifestyles are sustainable. However, many agricultural systems have caused a deterioration in the environment, face a persistent struggle to be profitable and are not sustainable. The urban majority in modern, affluent societies would prefer to maintain their life-styles: well sheltered and with a reliable supply of cheap, high quality food; they would prefer not to return to self-sufficient agriculture. However, urban societies will suffer also from failures of the agricultural systems to which they are coupled (Fig. 1).

Threats of a production-method to sustainability can be judged by its effects on components of agricultural systems (4):

- Soil (depth; fertility; structure; surface-salt; vegetation-cover; pesticide residues);
- Ground-water (depth; solutes; pesticide residues);
- Pests, diseases and weeds (species; biotypes; densities);
- Crops and pastures for food, fibre and other products (yields of high and reliable quality and inputs needed to sustain them);
- Farmers and rural communities (farm-equity; profit; choices of life-style and leisure)
- Technology (innovation and adoption);
- Education and research;
- Non-renewable resources (fossil-fuels; soil).

The condition of these components, and their causes, are inter-related since a change in one can bring about a change in another. Furthermore, in a sustainable system, all of the listed components must be maintained at satisfactory levels. Thus, a system would be unsustainable if weeds were kept at low levels but in so doing caused soil degradation or herbicide residues in the ground water. The difficulty, of course, is to define "satisfactory levels" and the time-frame for them to be achieved and maintained. In a wider context, sustainable agriculture should not be a threat to the sustainability of other systems, such as the biodiversity of ecological systems.

Improved technology to control weeds (cultural; chemical; biological) has made substantial contributions to modern agriculture and released people from laborious, menial tasks. As contributors to sustainable agriculture, methods for weed-control will need to be:

1. Effective, flexible, profitable and innovative;
2. Replace human labour with technology;
3. Circumvent the ability of weeds to adapt to selection pressures;
4. Safe to the environment and users of the methods;
5. Prevent the introduction and spread of weeds to new areas;
6. Contribute to the well-being and equity among people of different countries and of future generations.

However, weeds continue to threaten the sustainability of agriculture (11) and other systems of land-use (14) because these six requirements have not been met. Reasons for failures to control weeds include:

- Shifts in weed flora to species which are more difficult to control with current technology and agricultural systems;
- Species of weeds have become resistant to herbicides;
- Land and water resources have been degraded and polluted;
- Labour for manual methods has become scarce;
- People object to herbicide residues in agricultural produce and in the environment.

Analysis of these failures reveal that we have relied too heavily upon particular methods (herbicides; cultivation). Consequently, it is now advocated that weed control should use a range of control methods (chemical; cultural; biological) integrated into long-term management programs, so-called weed management systems (WMS) and, hopefully, these WMS will be sustainable.

A systems approach for WMS has been difficult to implement because:

- Single-method technology that has been effective and profitable (eg. herbicides; cultivation);
- People prefer simplicity rather than complexity;

- Research and extension on options for weed control has had a narrow focus, eg. chemical methods;
- Research and demonstration needs to be done on the:
  - Integration of options for weed control into management systems to show that they are more effective and profitable than simple controls when they assessed over the long-term;
  - Population dynamics (species; biotypes; numbers) of weed communities when subject to complex control programs;
- Methods for thinking and communicating about complex systems has not been utilised in weed science (see Appendix: A systems approach to WMS).

The evolution of herbicide-resistant weeds, soil erosion, and burdensome manual methods are current incentives for a change from current simple programs of control to more complex, long-term management systems. What is needed is the sustained allocation of resources to committed people who want to research and promote this change.

## CURRENT STRENGTHS IN WEED SCIENCE AND TECHNOLOGY

The development and practice of current methods of weed control over the last 50 years have resulted in many strengths. These strengths will be a sound base for the development of future systems.

*Education*: WMS of the future should not be learned by the slow process of experience, rather they should be developed and evaluated by the more rapid process of research by people educated in research and linked to the industries they serve. Weed science and technology is a specialised discipline and it is taught and researched in Universities to advanced levels. Graduates receive a broad education in disciplines related to weed science (eg. chemistry, botany, genetics, and economics) and, therefore, are able to participate in innovative, multi-disciplinary studies of WMS and their impacts on the environment. Societies of weed science and technology in local and regional parts of the world also are involved in education through regular conferences and workshops, and they have contributed to a large knowledge base through the publication of proceedings and journals of high international standard. Many countries have the capacity to train scientists and technologists for parts of the world where the education system is less developed. Increasingly sophisticated WMS will need, also, formal education of those who promote and practice the technology and in many countries the education-system is well developed.

*Research*: A research ethos and competency is widely developed and supported in many countries. Private and government organisations provide an infrastructure and environment for the practice of objective scientific inquiry. There is collaboration at the international level and a number of regional research organisations are funded by international agencies. Funding for research comes from governments, private companies and the agricultural industries. Research objectives are coupled to industry problems through advisory and management boards. Workshops are held to establish research priorities so that scarce resources are allocated to priority areas. There is a large body of established information and skills from which future advances will be built. Private industry develop technologies and products that are likely to generate profitable sales. Research funded by governments covers those areas which are in the interests of the community but which are unlikely to generate sales of commercial products in the short-term – such as basic research and conservation of the environment.

*Extension*: Two-way transfer of information on new technologies between research and practice is promoted by established methods and media and, increasingly, computers and the internet. Mass media raise the expectations of people to benefit from the new technologies. Evaluation that leads to adoption of new technology is limited more by opportunities for evaluation than awareness of its existence.

*Regulation*: Efficacy and safety to the user and to the environment can be established by the informed reaction of users in the market place. Government regulations, penalties and enforcement procedures have been implemented in many countries to ensure that only effective and safe technologies and products reach the consumer.

*Private industry*: Research, production and sales of new technologies and products are developed by well-established non-government companies. Major companies are multi-national and expensive research and development is initiated in the knowledge that costs can be recovered from sales world-wide – with regional adaptations.

*Farmers*: New products and technologies are adapted by farmers to fit their enterprises. Farm-families who adopt new technologies have recognised the need for formal education and off-farm training for their children so they can adapt to a future of change and sophisticated technology.

The path to more sustainable WMS will be to take advantage of current strengths to overcome weaknesses in priority areas.

*Transfer and adapt technology from high technology WMS to high labour WMS*: Countries less able to allocate resources to education, research and extension may be assisted by collaboration with colleagues in countries where these resources are a strength. Societies and organisations for training and research on a regional basis offer encouragement to those in countries with political instability and a lack of infrastructure for training and research.

*Research on weed biology*: Weed control has been, mostly, reactive to the presence of weeds. The development of WMS requires a proactive approach to the anticipation of weeds and their response to control-measures. Annual and perennial weeds recover from damage by new growth from seed residues and other propagules, and by regrowth. Less obvious, in the short-term, is a response to persistent damage by a shift in the flora to species more tolerant to the control measures and the selection of genetically resistant biotypes. Knowledge of these aspects of the population dynamics of weeds can be used in the development of WMS so that progress to resistant species and biotypes can be avoided and managed. Sustainable WMS will be most difficult in annual cropping systems where weeds, by their nature, are adaptable to the predictable disturbances of the cultural practices and the weather.

*Herbicide resistant crops*: Genetically engineered crops with traits for pesticide resistance and food quality, often with genes from other species, is a remarkable confirmation of knowledge on the basic biology and chemistry of plants. Herbicide resistant crops offer the hope for continued use of safe and effective herbicides in low-labour WMS (10).

*Computer technology*: Microcomputers with high speed and capacity, and at low cost, have revolutionised communication and personal productivity. Information and self-paced learning are available to all who have access to the technology; on-line instruction can overcome the needs for personal tuition. Courses developed by individuals and teams can be made available to a world-wide audience. Computer-based expert systems (21) can be used by those with problems for diagnosis and advice on the integration of methods for a WMS. Precision agriculture will use computer technology to pursue the use of minimal inputs for maximum productivity.

*Biological control*: Self-perpetuating, selective control of weeds by introduced agents (insects, diseases, animals) has had dramatic success. Research on interactions between the host (weed) and biocontrol agent have developed strengths, which will improve the probability of successful releases of agents. Biological control of weeds is particularly attractive, and more likely to be successful for natural ecosystems and extensive, low input agriculture of marginal profitability. There is renewed interest in the grazing animal as an agent to control crop-weeds which have become resistant to herbicides in a pasture phase of cropping systems in temperate Australia.

*Herbicides*: Private industry continues to invest in the discovery of effective and safe herbicides. This research and development is an increasingly costly process but greater efficiency is derived from established competencies and infrastructures, and a substantial knowledge base derived from basic and applied research. The goal remains to design new herbicides from knowledge of processes in the plant and molecule-configurations likely to inhibit them. Expanded uses of existing herbicides with a proven record of safety and effectiveness may offer a less costly route to new options for chemical weed control, for example the selective uses of otherwise non-selective herbicides through genetically engineered resistance in crops.

*Environment*: Increasingly educated urban and rural societies expect ecologically sustainable developments and can exert pressure on governments and industry to achieve this goal. These expectations are manifest in government regulations and penalties which aim to prevent malpractices which may damage the environment and human health. Sound and ethical research, development and practice, subject to open peer review, can ensure that only safe and effective technology is adopted; regulation acts then as a safeguard in an otherwise self-regulating society with adherence to codes of best practice.

*Integration of multiple options*: Resilient and adaptable communities of weeds can circumvent simple control-methods that are used repetitively. The challenge is to select, and develop, a range of options and integrate them into complex management programs for long-term, profitable weed control which do not exceed acceptable off-target effects. Long-term field research is needed to meet this challenge. Retrospective analyses of benchmark communities in land management systems, for which good records are kept, can be used in this research.

*Economics*: WMS must contribute to the financial viability of farmers over the long-term and, through public funding, the maintenance of natural ecosystems. Farming systems of all countries need cheaper costs of production and weed control, as a major cost, must meet this challenge. Short-term profits encourage over-use of the cheapest labour-saving technology and, given the ecological nature of weeds, ultimately it becomes ineffective.

## THREATS TO THE DEVELOPMENT OF SUSTAINABLE WEED MANAGEMENT SYSTEMS

Challenges exist for the development of WMS and there are strengths in weed science and technology to meet these challenges. We can be optimistic that, when based upon sound ecological principles, WMS can be long-term programs which keep weeds under control and promote improvements in the environment. However, WMS must be flexible so that farmers and managers of natural resources can adjust to changes in markets, and to the resources and technology available to develop and implement the programs. WMS must also contribute to farm-profitability and human well-being. Thus, WMS operate in dynamic and somewhat unpredictable circumstances and, therefore, there will be an on-going need to modify WMS or they will not meet the criteria set for sustainability. Some threats can be identified to the research and development (R&D) that will be needed to keep WMS effective and profitable:

*Funding of research and development*: The development and maintenance of WMS requires on-going, long-term research. In more developed countries (MDCs) with a history of R&D there is need to sustain leadership in R&D – particularly basic research. Elsewhere, in the lesser developed countries (LDCs), the immediate need is to develop local and regional competencies and infrastructures for adaptive R&D. These needs for R&D require long-term funding. However, in MDCs there is a decline in public funding of R&D, while industry expects shorter-term returns to their investments in R&D which they can capture through the sale of products protected by patents. Investment in R&D for WMS is unlikely to generate marketable products, it is about the integration of technologies into management programs. Consequently, funding of the R&D for WMS needs a mix of public and private investment, and a commitment for the long-term.

*Concerns for the environment*: By its nature agriculture disturbs the environment and labour-saving technology for WMS has introduced new chemicals (pesticides; fertilisers; growth regulators) which may not exist in nature. There is a need for rational, objective and balanced assessments of the risks, benefits and ethics of technology and decisions made, and enforced, which are ethical and in the common good. Structures need to be set-up so that these assessments are made in an open and participatory manner. Failures to meet these requirements may discourage investment in the R&D needed to develop new technologies, and systems for their use, or the rejection of existing technologies on unreasonable grounds. The needs of a rapidly increasing, urbanised populations must be met by increased productivity from diminishing land and natural resources. The technology required to meet these needs for increased productivity will heighten the concerns about technology by societies which are becoming better informed, articulate, organised and critical in their thinking. Moves towards privatisation of government services and the deregulation of markets add to these concerns.

*Training*: The development and implementation of WMS is concerned with complexity rather than simplicity; multi-factor rather than single-factor research and practice; dynamic, flexible systems rather than static, repetitive practices. These realities place demands on scientists and technologists, and on farmers and their advisers. These demands should feed-back into the training they receive. In MDCs and LDCs it is difficult to maintain enrolments in courses in agriculture and related disciplines, and to attract the most able students into them. As LDCs become more industrialised graduates are attracted away from agriculture and into non-agricultural businesses and technologies. In MDCs farmers are becoming older and rural youth often pursue higher education as a means of escape from agriculture. Clearly, there is a need to make young people aware of the joys and challenges of a vocation and career in agriculture and related disciplines.

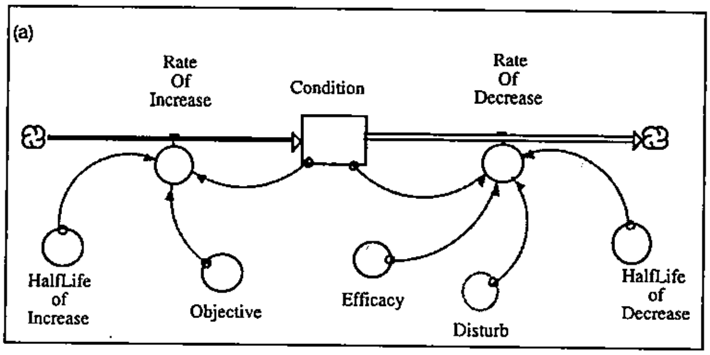
## CONCLUSIONS: SUSTAINABLE WEED MANAGEMENT – FACT OR FALLACY?

The topic for this paper is a serious question set by the organisers of an international conference. Of concern is that the answer to the question "fact or fallacy?" is equivocal for both low and high technology systems of food production and land care. Consequently, there are urgent needs for technological innovations and adaptations, and their integration into WMS. Some of these changes will be profitable for private industry to develop but the research and development of management systems for private and public lands needs government funding. However, in many developed economies, government cut-backs will delay this work (8) until the fallacy of sustainable WMS becomes of greater concern to the urban majority.

WMS have been described for many cropping systems (22). However, most WMS are word-descriptions of the technology options. Development and promotion of WMS would benefit from the use of systems theory and computer-technology to research, communicate and simulate the dynamics of WMS systems. University curricula, research and extension all need to adapt so they can develop and promote WMS. Graduates need to be equipped with knowledge, skills and commitment to develop WMS, and the belief that they can be creative in their contributions. They will need sustained resources to carry out their work and the guidance and encouragement of skilled and experienced leadership. WMS will be developed by people and fallacy can turn to fact if they are well trained, resourced and committed to the task, There is evidence in both MDCs and LDCs to show that the task is urgent.

## APPENDIX: A SYSTEMS APPROACH TO WEED MANAGEMENT SYSTEMS

*A Generalised Systems Approach*: Weed management systems (WMS) operate within farming systems. Both systems involve change and, therefore, must satisfy concerns for ecologically sustainable development within socio-economic systems. It is fortunate that within this complexity a common structure for all systems can be recognised (Fig. A1). This common structure provides a basis for the analysis of particular systems.




The 'condition' of a component of a system (Fig. A1a) may be the Quality and Quantity of Weeds; Farm Profit and Life-style; Environmental Quality; Innovation and Adoption of Technology (Table A1). The objective for WMS should be to devise effective disturbances which would defeat the innate resilience and adaptability of weeds, so that they fail to recover condition, yet allow recovery of the environment. A system is sustainable if conditions of concern (the environment) recover after disturbance (effective weed control) to acceptable levels (objectives) within acceptable times. Sustainability depends upon both the dynamics of recovery and nature of the disturbance.

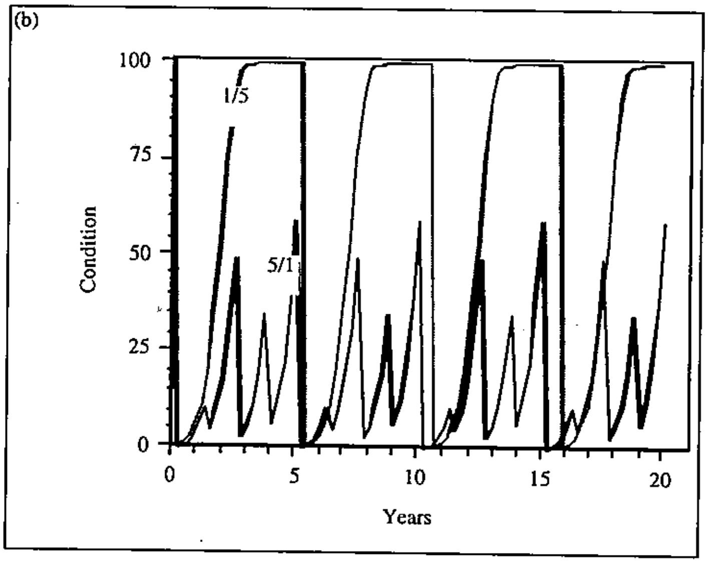



Fig. A1. The structure (a) and behaviour (b) of a system. As the 'condition' was decreased through frequency of disturbance, from once in five years ( 1/5 ) to five times in one year ( 5/1 ), recovery failed to reach the objective of complete restoration of the condition and the system, by definition, became unsustainable.

*A Systems Approach for WMS*: Application of a systems approach to WMS involves six key, recursive steps (Fig. A2).

1. Identify indicators (preferably predictors) of the state (condition) of the system and what causes them to change, ie. to increase and to decrease (Table A1).
   It is important to identify feedback loops which accentuate or attenuate change, and indirect causes and effects (Fig A3).
2. Define objectives for states of the indicators (high for the environment, low for weeds).
3. Assess (measure) discrepancies between objectives and present states.
4. Identify causes of change in the structure of the system which can be manipulated by management to eliminate discrepancies between objectives and present states.
5. Manipulate (manage) the system and observe progress towards objectives.
6. Refine, or redefine, steps 1 - 5.

Fig. A2 Six recursive steps in a systems approach to the development of weed management systems. Structural diagrams of a system are shown in Figs. A1a and A3a. Assessment of discrepancies (step 3) is by observation or simulation (Figs. A1b and A3b, c), or by both methods.

The discrepancies (step 3, Fig. A2) will change over time (Fig. A1b) and, therefore, need to be monitored. Management needs to react to the earliest indication that discrepancies have increased. It is important to emphasise that change is frequently exponential ('the bigger it is the faster it gets bigger') and a delayed response can lead to a population explosion (12) or unexpected damage to the environment. Furthermore, the correct response, most probably, will not be more of the current control program from which the weeds have escaped. Sustainability is a changing, elusive goal and its pursuit requires on-going application of the six recursive steps (Fig. A2).

*Indicators (predictors) of the sustainability of WMS (Fig. A2 step 1)*: Some would claim that weed scientists failed to warn farmers that repetitive use of herbicides could produce herbicide-resistance weeds. Through experience and research we have now better practices to manage herbicide resistance and, as importantly, methods by which those in other farming systems may avoid (or delay) the problem. This applies particularly to farmers less advanced in the adoption of herbicide technology. However, an important question remains for the design and maintenance of WMS: Are there indicators we can include in the analyses of WMS (Figs. A1, A2, A3) which will be general predictors of the adaptability of weeds to management systems? In a general sense we have the answer to this question. Weeds have co-evolved as threats to our management systems because of their adaptability to the 'disturbances' of systems devised to nourish and protect domesticated species. Consequently, we need to include in the consideration of WMS not only our reactions to the obnoxious nature of weeds (competition; thresholds; control methods) but also the adaptability of weeds to selection pressures (11, 15). Predictors of adaptability will come from a knowledge of weed ecology, particularly the genetics and dynamics of weed populations. This requires us to change our ways of thinking about agriculture as short-term input/output systems (an anthropocentric view of ecosystems) and operate as integral parts of ecosystems (an ecocentric view) which we manage within sustainable boundaries and do not disturb them massively, and irreversibly, by our management systems.

Sustainability will be longer-term if we anticipate adaptations, look for early indications of them, and modify the management-system to discourage the exponential phase of the adapting species. As well, we should devise management-systems that discourage adaptations. This can be done (ecocentrically) if the necessary disturbances by agricultural systems frustrate adaptable species through the unpredictable nature of the disturbances. Knowledge on the specifics of weed x disturbance interactions that lead to successful invasions and expansions is limited (13, 15). Consequently, as an operational objective in WMS, the use of predictors of weed adaptations may not be practical with current knowledge of weed ecology. It would be better, therefore, to adopt objectives that, in general, discourage adaptations (eg. unpredictability) even though they may impose unnecessary constraints (sufficient but not necessary):

- Avoid high selection pressures: Repetitive (predictable) use of the same effective control methods on high densities of genetically adaptable weeds.
- Avoid high risk methods: High efficacy; broad spectrum of controlled species; selection for heritable traits which would negate the control methods.

These objectives are a generalised form of those for the avoidance of herbicide resistance.

Those concerned with quarantine and eradication (13) also must make decisions with insufficient knowledge on the invasiveness and adaptability of weed-threats. Decisions are based upon climatic similarities of infested and threatened regions (homoclines as predictors of likely success in new habitats) but we lack knowledge of the ecology of invasiveness and how the potential weeds may react to management-systems in new environments (12).

Thinking about WMS may begin with the familiar approach of a list of causes and effects (Table 1). However, we need to advance beyond such lists and identify the feedback between states (conditions) and the causes of their change. Lists of causes and effects (Table A1) fail to identify feedback-loops between the items (effects on causes; effects on effects). Thus, within the weeds sub-system the quality and quantity of weeds (effects) feed-back on the causes of their change. Furthermore, sub-systems are connected through feedback. For example, the outcomes (effects) of the technology sub-system will, through feedback *via* efficacy (Fig. A3a), influence the causes of change in the weeds sub-system. Feedback-controls abound in natural and managed ecosystems but we seldom identify them. Yet, they have profound effects on the dynamic behaviour of the system (Figs. A1, A3), and the analysis and management of any system would be incomplete without them. However, for reasons of simplification, some conditions may be considered unimportant and outside the boundaries of an analysis. Thus, a WMS may be developed without the inclusion of other sub-systems (such as those shown in Table A1) and assume they are unimportant within the context of the WMS, or take their inputs without attempting to develop a sub-system for them. For example, a WMS may be developed for the short-term under assumptions of current technology, present skills and knowledge, and acceptable environmental disturbance.

A structural diagram (Fig. A1a) takes a cause-effect list (Table A1), identifies the feedback loops between the items (Figs. A1a and A3a) and makes it possible to investigate the system's behaviour through computer simulation (Figs. A1b, and A3b, c) and physical experiments. It can be anticipated, however, that progress beyond qualitative lists (Table A1) and structural diagrams (Figs. A1a, A3a) to dynamic simulation (Figs. A1b and A3b, c) will be frustrated by a lack of knowledge of weed ecology (7) within the context of WMS. Given our lack of knowledge, there is great benefit to be derived from a coupling of investigation through simulation with physical experiments (5). However, it may not be possible to investigate some systems by physical experiments and simulation becomes an alternative method (20).

Table A1. An incomplete list of causes and effects in weed management systems. Feedback between effects and causes within and between sub-systems need definition and some are shown in Fig. A2a.

| Causes of ... | Effects (Conditions) |
|---|---|
| **Weeds Sub-system** | |
| ... Increase: | |
| Available resources; Propagules; Competitiveness; Adaptability; Resilience | Quantity & Quality of Weeds: Biomass; Species; Biotypes |
| ... Decrease: | |
| Efficacy: Chemical; Cultural; Biological; Ecological; Combined methods; New technology | |
| **Environment Sub-system** | |
| ... Increase: | |
| Pest control; Minimum tillage | Environmental quality: Soil; Water; Air; Energy; Food; Shelter; Biodiversity |
| ... Decrease: | |
| Weeds; Pesticides; Cultivation; Efficacy | |
| **Profitability Sub-system** | |
| ... Increase: | |
| Productivity; Quality; Prices | Farm profit & life-style |
| ... Decrease: | |
| Costs; Weeds; Efficacy | |
| **Technology Sub-system** | |
| ... Increase: | |
| Education; Research; Profits; Incentives; Efficacy | Innovation & adoption of technology |
| ... Decrease: | |
| Funds; Skilled people | |

*Objectives for indicators (Fig. A2 step 2)*: In managed systems, objectives (O) are desired levels of the indicators of the state of the system. If, over the long-term, management can maintain the state of the system within acceptable limits of the objectives then the management system may be judged sustainable. Thus, objectives for the WMS may be over the long-term (25 years) to maintain at satisfactory levels:

1. Weeds;
2. Environment;
3. Farm profit;
4. Efficacy of weed control.

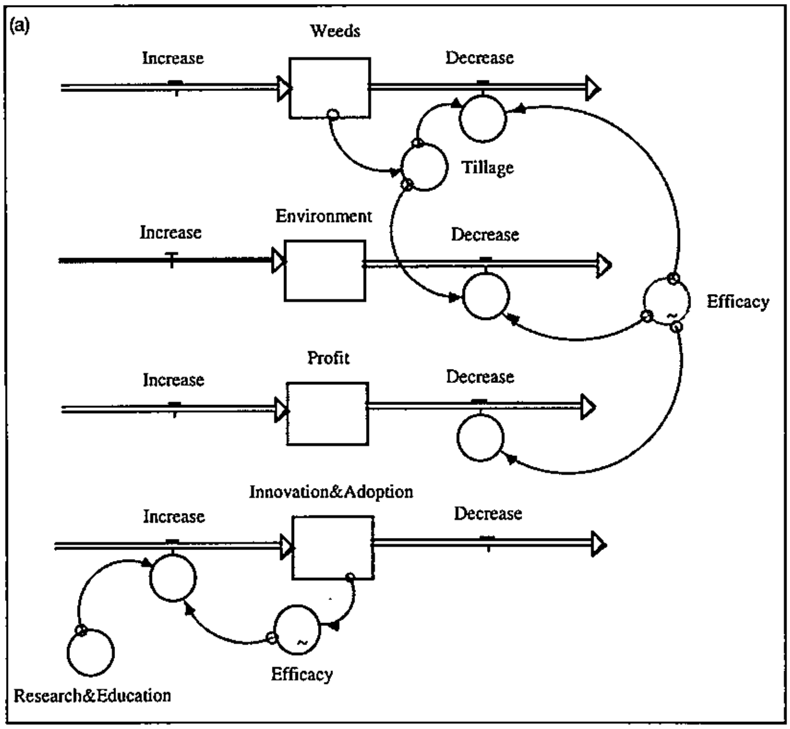
The simulation model (Fig. A3) shows these levels on a scale of 0 - 100 (components 1 - 3) and efficacy on a scale of 0 to 1. Levels nearer to full-scale would be mores 'satisfactory' than low levels.

*Measurement of discrepancies (Fig. A2 step 3)*: If the state of the system (S) deviates from the objectives by unacceptable amounts then a discrepancy, D, exists (D = O - S) and the system would be judged unsustainable – unless the discrepancy can be overcome within an acceptable time and without damage to other components of the system. Measurement of a discrepancy requires operational definitions of O and S so that the manager recognises D with ease and accuracy. Weeds at high levels (Fig. A3c) would be an obvious discrepancy for a management response but a discrepancy in Innovation&Adoption would be more difficult to monitor – yet, through its effect on Efficacy of weed control, it is the cause of declines in the other three components of the system.

*Responses to discrepancies (Fig. A2 steps 4, 5)*: In a managed ecosystem, if the manager recognises D then a decision is made to take measures to close the gap between O and S. In self-regulating ecosystems (eg. biological control) the internal controls within the system determine the responses to D.

In linear systems the rate of response (R) to D can be written as R = K x D, where the parameter K is the rate constant and is a measure of the responsiveness of the rate to unit discrepancy (K = R/D). Dimensionally, K is the reciprocal of the half-life, HL = 1/K (approximately). Thus, a responsive rate has a small HL. The ability of a state to recover from a disturbance, its resilience, depends upon the HL of recovery relative to the HL of disturbance. Thus, the dynamics shown in Fig. A1b show a condition at risk as the frequency of disturbance increased (due to natural causes or management-decisions).

The simulation of a WMS (Fig. A3b, c) shows two scenarios, one where Research & Education (R&E) was run at 0.75 (Fig. A3b) and another at 0.25 (Fig. A3c). If the current input to R & E is low then the simulation indicates that there is a need for an early response to increase it. However, in reality, a manager would find it difficult to argue for greater R&E in the early years since the dynamics of Efficacy over the first five years of the simulation at the two levels of R&E both show improvements (Fig. A3b, c). It is only in later years that the consequences of low R&E begin to show.



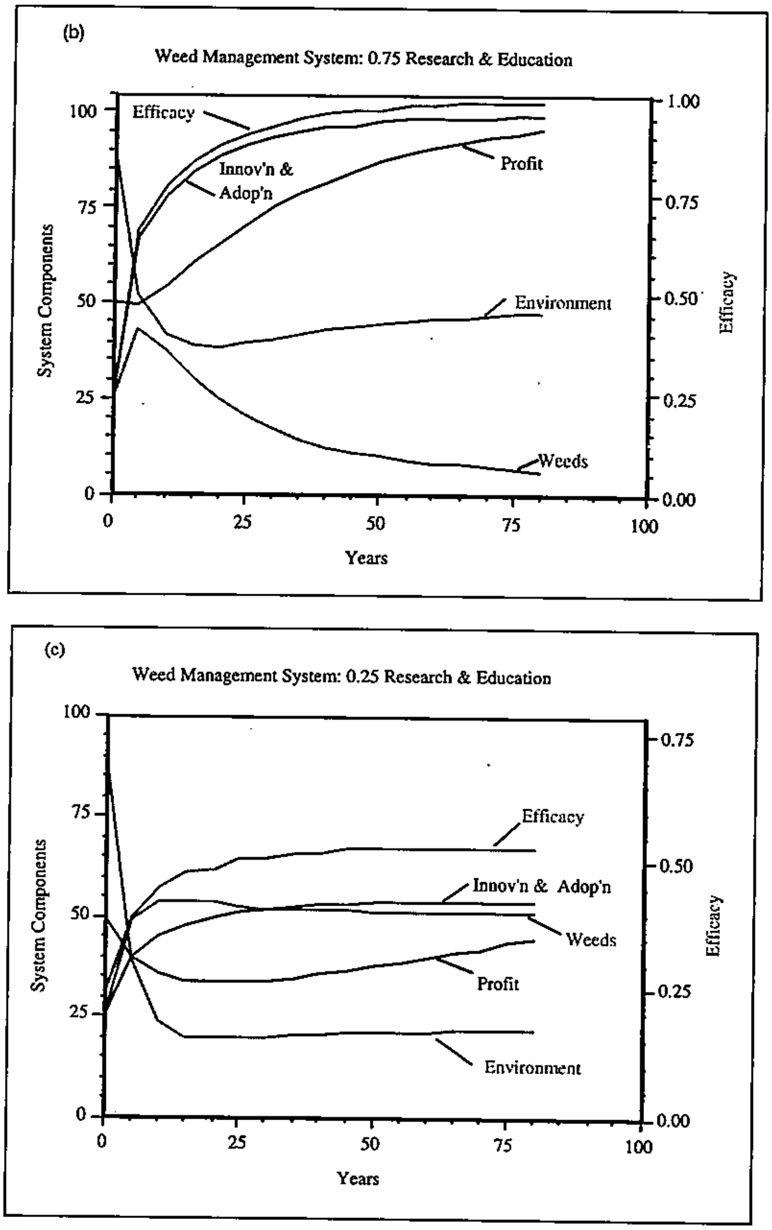



Fig. A3 Analysis (a) and simulation (b, c) of the dynamics of a Weed Management System to show the need for a high level of Research & Education (b) to keep weeds under control through innovation and adoption of technology. Only some of the details of the system are included to show how the four sub-systems are linked through Efficacy of weed control. When Research & Education was at a low level (c) there was a decline in innovation and adoption of new technology and a consequent decline in Efficacy of current technology to control resilient and adaptable weeds. Attempts to control weeds by increased tillage (c) caused a decline in farm profit and the environment.

*Implications for Education and Research of a Systems Approach to WMS*: The need for management in WMS is not only to establish O (for which S needs to be defined) and recognise D but, also, to be responsive to a recognised D. However, responsiveness of management to D is subject to delays (finite half-lives) also. The reasons for delays in weed management decisions may be due to other priorities in the farming system. They may be due also to a lack of awareness of the consequences if responses to D are too slow. Research and extension may be needed to convince managers that they need to take sound actions to control weeds within the critical periods for weed control. Critical periods are described by S and O and there are research and extension needs to have them defined and adopted also.

The analysis of complexity and the integration of control-methods into WMS would be accelerated by formal, tertiary education of researchers and agents of extension. Specifically, there are needs to include in the education of weed scientists:

- How can systems be analysed?
- How are systems structured and how do they function?
- How can the dynamic behaviour of complex systems be simulated with computer models?

- How can simulation models be used as research and extension tools?

A systems approach can be applied qualitatively as a frame-work for thinking and communicating about systems. However, if an objective is to develop quantitative simulation models as research and management tools in WMS then studies of weed ecology within the context of simulation models (7) will need to become education and research priorities also.

In some parts of the world, including Asia and the Pacific, there is a high participation in University education (18) and the suggested content may involve modifications of existing curricula only. In many parts of the world, however, there is an urgent need to increase participation in University education (2, 18) as well as to design the curricula. Modifications of existing systems of weed management would be assisted not only by formal education but also a sensitivity to the existing technical and cultural systems that need to be changed (1, 17, 18, 23). In countries which have high and diverse inputs of technology in their WMS there is a need to re-think their curricula also. Researchers and advisers have been part of a technology x culture system that has failed to prevent the deterioration of agricultural systems and the environment, and urgent attempts are being made to improve the situation (3, 4, 9). However, there is grave concern about the reduction in public-funding for the research and development that is needed to develop WMS (8). Expectations remain for the technological quick-fix (25) which continues to offer hope (8, 10). Graduates from the education-systems need to have the skills and expectations to 'get in front' rather than to stay the same or to catch-up.

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# ADVANCES IN WEED-CROP ECOPHYSIOLOGICAL RESEARCH AND THEIR CONTRIBUTIONS TOWARDS ATTAINING SUSTAINABILITY IN AGRICULTURAL PRODUCTION SYSTEMS

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*Summary*: Sustainability in agricultural production systems demands for weed management with a reduced dependency on herbicides. This can only be realised if suitable alternative weed management options, be it preventive measures or curative weed control techniques, are available. Insight in processes related to crop-weed interactions and weed population dynamics might help in the development of preventive measures and to identify new opportunities for weed control. Furthermore this insight can be used to improve operational and tactical decision making and to design and explore long-term strategies for weed management. The complexity of the processes involved in crop-weed interactions and the long-term character of weed population dynamics hints at the use of simulation models. In this paper the state of the art of weed-crop ecophysiological knowledge is briefly described and its contribution to the development of sustainable agricultural production systems by improving present-day weed management systems is discussed.

*Keywords*: management strategies, computer simulation, weed-crop interactions

## INTRODUCTION

In most agricultural systems, weed management has been one of the major issues determining the design of cropping systems, especially before herbicides became available. The use and application of herbicides was one of the main factors enabling intensification of agriculture in developed countries in the past decades. More recently, the availability of herbicides has been coupled to intensification of agriculture in developing countries as well. A well-described example is the recent area expansion of direct seeded rice in Asian countries; a technology not widely practised before the late seventies largely because of weed control problems and now becoming a major system in Asian tiger economies, like Malaysia and Korea, where labour shortage is pressing.

However, increased concern about environmental side effects of herbicides, the development of herbicide resistance in weeds and the necessity to reduce cost of inputs have resulted in greater pressure on farmers to reduce the use of herbicides. This has led to the need for the development of strategies for integrated weed management (IWM). Rather than trying to eradicate weeds from a field, emphasis is on the management of weed populations. The development of such weed management systems requires thorough quantitative insight into the behaviour of weeds in agroecosystems and their effects.

In Fig. 1 a simplified scheme for the relations between weed problems and weed management options, which broadly can be classified into preventive and curative measures, is presented. If only the short-term perspective is considered, decision making mainly involves operational decisions on if, when, where and how weeds should be controlled. For this type of questions quantitative insight into crop-weed interactions is highly relevant, when another threshold than 0 is used. If weed problems are examined on a longer-term perspective, the first step in the decision making process deals with strategic decisions, which set the framework for tactical and operational decisions. Apart from the effect of the weeds in the present crop, the potential consequences for future crops are accounted for. For such considerations knowledge on the dynamics of weed populations in space and time becomes pertinent. Irrespective of the time dimension of the analysis, it is clear that attempts to reduce the present dependency on herbicides should focus on prevention, through for instance cultural measures that favour the crop or through the use of more competitive varieties, on the development of better curative control techniques and on better long- and short-term decision making. This becomes even more important when precision farming techniques enable us to control weeds site specifically and development stage specifically. Quantitative insight into both crop-weed interactions and the dynamics of weed populations in space and in time forms the basis for such explorations of opportunities to improve weed management. Because of the complexity of the processes and the long term aspects in population dynamics, models are required to obtain such quantitative insight and to make the knowledge operational.

This paper reviews the state of the art with respect to insight in crop-weed interactions and weed population dynamics and discusses possibilities to use this knowledge to design improved weed management systems that add to the development of more sustainable agricultural production systems.

*Integrating ecophysiological understanding of crop weed-interactions*: Competition is a dynamic process that encompasses the capture and utilisation of shared resources (i.e. light, water, nutrients) by the crop and its associated weeds. In case of crop-weed competition, focus is on the effect of resource capture by weeds on crop growth and production. Those resources of which supply cannot meet demand are of major interest, as they determine the attainable yield of the crop. If weeds capture such resources, crop growth will be reduced resulting in yield loss. Quantitative understanding of crop-weed interactions seems a solid basis for the improvement of weed management systems in different ways. Ecophysiological models that simulate the uptake and use efficiency of resources by the competing species provide insight into the outcome and the dynamics of competition and may aid in seeking options to manipulate competitive relations in agro-ecosystems.

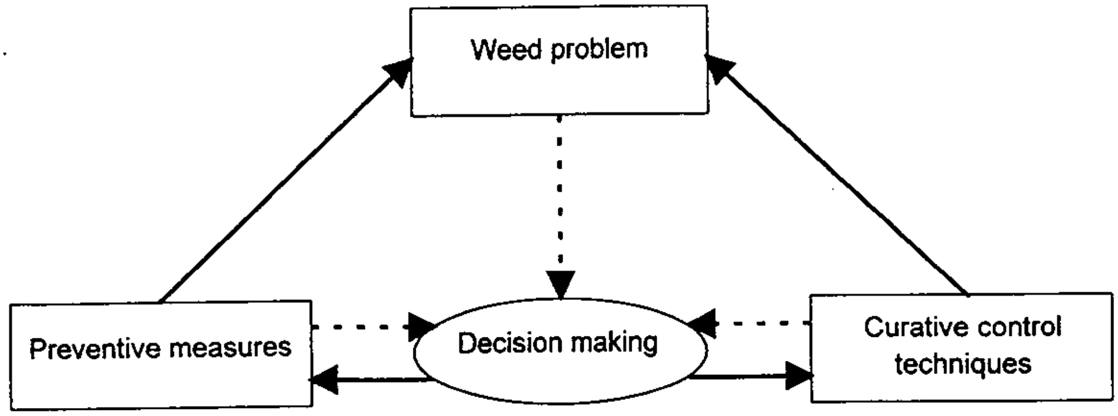


Figure 1. A simplified schematic representation of the relations between weed problem and options for weed control. Weed management can be enhanced through improved preventive or curative control measures or improved decision making. Broken lines represent flows of information, solid lines indicate operations.

Various competition models have been developed (15, 19, 20, 40, 49). The ecophysiological model INTERCOM described by Kropff and Van Laar (19) consists of a set of individual growth models (one for each competing species), that calculate the rates of growth and development for species based on environmental conditions (Fig. 2). The growth models are expanded to account for morphological processes that only affect growth in competition and coupled to account for the simultaneous absorption of available resources by the different species in a mixed vegetation. Under favourable conditions, light is the main factor determining the growth rate of the crop and its associated weeds. In INTERCOM, the quantity of photosynthetically active radiation absorbed in mixed canopies by each species is a function of the amount and vertical distribution of photosynthetic area within the canopy, and the light extinction coefficient of the species. A water balance for a free draining soil profile is attached to the model, tracking the available amount of soil moisture during the growing season. When available soil moisture drops below a critical level, transpiration and growth rates of each species are reduced. Since transpiration is driven by the absorbed amount of radiation and the vapour pressure deficit inside the canopy, competition for water is closely linked to aboveground competition for light. The more light a species absorbs, the more water is required for transpiration. Direct competition for water as a result of differences in rooting density is not accounted for. An extension of the model for simulation of competition for nitrogen has been described, but has not yet been implemented.

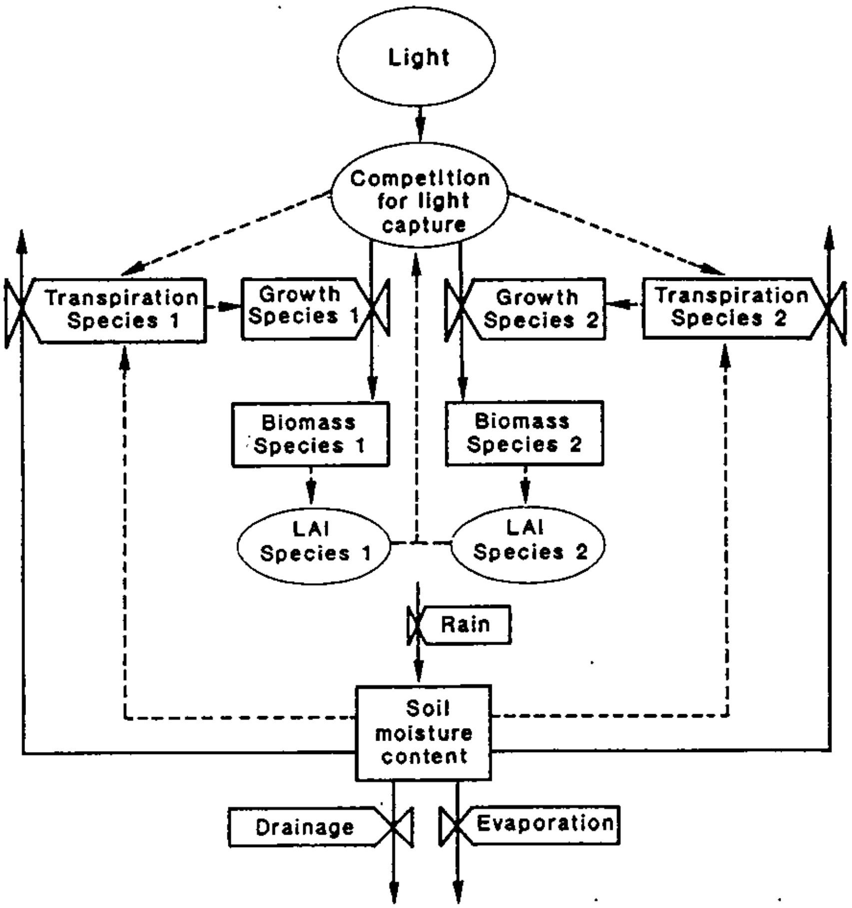


Figure 2. General structure of the eco-physiological model for interplant competition (INTERCOM) (19).

The ecophysiological competition model has been tested with data from competition experiments with maize (*Zea mays* L.) versus yellow mustard (*Sinapis arvensis* L.) and barnyard grass (*Echinochloa crus-galli* L.) (20, 38 40, 48), tomato (*Lycopersicon esculentum* L.) versus pigweed (*Amaranthus retroflexus* L.) and eastern black nightshade (*S. americana*) (21, 47), sugarbeet (*Beta vulgaris* L.) versus fat hen (*Chenopodium album* L.) (22) and rice versus *E. crus-galli* (19). The results of these studies indicate that interplant competition for light and water can be well understood from the underlying physiological processes. Several approaches to introduce spatial variability in the models are underway for row crops and complex vegetations. The main gaps in knowledge are related to morphological development and especially the phenotypic plasticity of weeds with respect to these morphological features. Kropff & Van Laar (19) for example studied the plasticity of *C. album* with respect to height development in relation to dry matter growth which was varied by growing the weeds in different competition situations. *C. album* demonstrated an impressive capacity to overtop the crop (sugarbeet) in spite of an unfavourable starting position due to late weed emergence by minimising its specific stem length.

Applications of these models can be found in the analysis and extrapolation of experimental data, the analysis of the impact of sub-lethal control measures (like low-dosages of herbicides and bio-herbicides), risk analysis for the development of weed management strategies, the development of new simple predictive models for yield loss due to weeds and the design of new plant types for weed suppression. These last two applications are briefly discussed.

*Development of new simple tools for early-season prediction of yield loss due to weeds*: The most widely used regression model to describe effects of competition at a certain moment is the hyperbolic yield-loss weed density model (6):

$$Y_L = \frac{aN_w}{1 + \frac{a}{m}N_w} \qquad (1)$$

where $Y_L$ gives the yield loss, $N_w$ is the weed density, $a$ describes the yield loss per unit weed density as $N_w \rightarrow 0$ and $m$ the maximum yield loss. This hyperbolic yield-density equation fits well to data from experiments where only weed density is varied (6, 20). However, parameters $a$ and $m$ are not constant for a specific crop-weed combination, but vary strongly from site to site and year to year. This instability is due to the effect of factors other than weed density on the competitive relationship between crop and weeds (19). Experimental results and analyses with the ecophysiological model identified the prominent role of the period between crop and weed emergence on the outcome of competition. This indicates that a more robust prediction of yield loss on the basis of early observations would only be feasible if this factor would be accounted for. For this purpose, some workers introduced an additional variable in the hyperbolic yield-density equation that represents the effect of differences in the period between crop and weed emergence (8). However, in practice weeds often emerge in successive flushes, making it difficult to apply a descriptive model that accounts for the effect of both weed density and the relative time of weed emergence: every flush has to be regarded as if it was a different weed species.

Supported by the analyses of the ecophysiological model for competition and based on the well-tested hyperbolic yield-density model, an alternative descriptive regression model for early prediction of crop losses by weed competition was derived (18; 23). This model relates yield loss to relative weed leaf area ($L_w$ expressed as the share of the weed species in total (crop and weed) leaf area) shortly after crop emergence, using the 'relative damage coefficient' $q$ as the main model parameter next to the maximum yield loss $m$:

$$Y_L = \frac{qL_w}{1+(\frac{q}{m}-1)L_w} \qquad (2)$$

Because leaf area accounts for density and age of the weeds, this regression model accounts for the effect of weed density and the effect of the relative time of weed emergence (18). The example in Fig. 3 clearly demonstrates the superiority of relative weed leaf area over plant density as an explanatory variable in descriptive yield loss models, especially if results from more than one site and year are simultaneously examined. However, a simple model like this, of course, can not explain the complexity of effects of environmental factors on yield loss by weeds. Lotz *et al.* (29) found that the relative leaf area model was superior to the density model but could not explain yield loss differences across sites exactly.

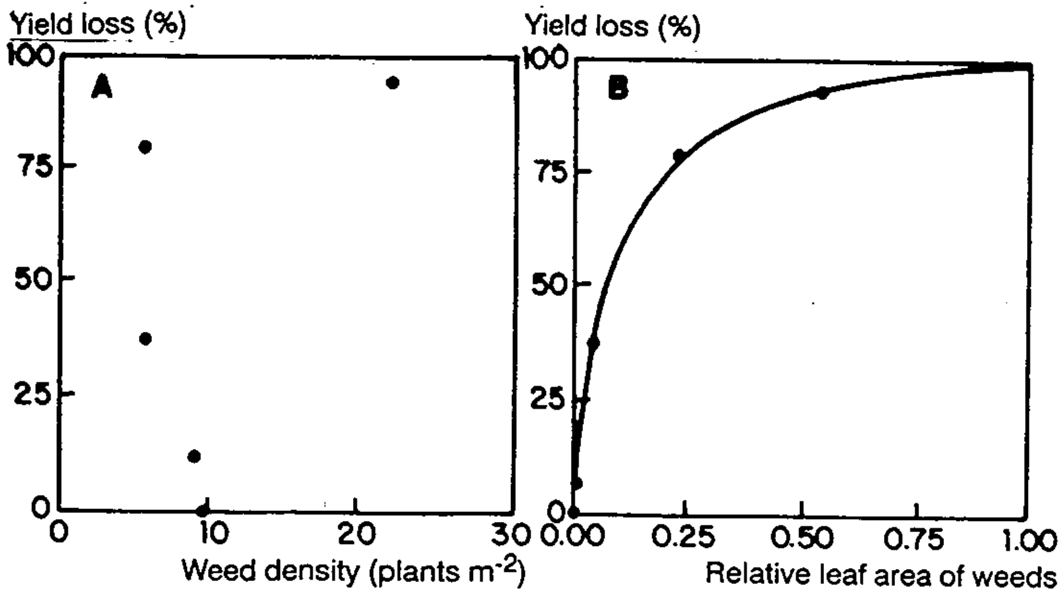


Figure 3. (A) Relationship between weed density and yield loss for five field experiments with sugar beet and C. album; (B) relationship between relative leaf cover of the weeds 30 days after sowing and yield loss for the same five experiments (19).

*Designing cultivars that are more competitive against weeds*: The development and introduction of crops or cultivars with an improved competitive ability might help reduce the present dependence on herbicides. Procedures for selecting genotypes with an improved competitive ability can be categorised into two main classes (26). One involves direct selection of genotypes in the presence of weeds. This type of selection can only be applied in the later stages of a breeding program when sufficient seed is available. Furthermore, experimental analysis of the competitive ability of a wide range of genotypes is very labour intensive and expensive (43). Indirect selection is an alternative in which selection is aimed at attributes, such as plant height, that are associated with competitive ability. Selection can thus be started early in the breeding program and can be carried out in the absence of weeds. Traits contributing to competitive ability need to be identified prior to the actual selection, and the contribution of different traits and their trade-off with yielding ability should be determined. This is where ecophysiological models for crop-weed interactions can contribute. Recently, the usefulness and limitations of ecophysiological competition models in designing more competitive cultivars were discussed, using rice as an example (4). Differences in competitive ability between two contrasting rice cultivars (IR8 and Mahsuri) were experimentally determined at the lowland research site of the International Rice Research Institute (IRRI) in Los Baños, Philippines. Mahsuri is a native cultivar that originates from Malaysia. It is a late-maturing, tall growing cultivar, with fast growth at early stages. IR8 is the first IRRI-bred semi-dwarf rice cultivar. It is a medium-maturing cultivar, with low stature and a high harvest index relative to Mahsuri. Both cultivars were grown in monoculture for quantification of various phenological, physiological and morphological traits, which were then translated into parameters that fit into INTERCOM. In monoculture IR8 had a lower shoot dry weight (-15%), but a higher grain yield (+36%) than Mahsuri. Growing the cultivars in competition with purple rice, which was used as a model-weed, and comparing the performance of cultivars in mixture and monoculture was used to determine the competitiveness of each cultivar. In mixture, dry matter production of IR8 was far more affected than the dry matter production of Mahsuri, demonstrating the higher competitive ability of the latter cultivar. The accurate simulation of competitive ability of both cultivars indicated that the observed differences in phenology, physiology and morphology between both cultivars were able to explain their differences in competitive ability (Fig. 4). An estimation of the contribution of various traits to overall competitive ability was made by analysing the experimental results with the help of INTERCOM. The importance of each trait was determined by constructing hypothetical isolines of IR8; for each isoline the original value of a single trait of IR8 was replaced by the value measured for Mahsuri. Model analysis revealed that the greater competitive ability of Mahsuri was mainly due to a greater relative leaf area growth rate early in the season and larger maximum plant height.

Competitive ability of rice has often been reported to be negatively correlated with yield potential and the presently used cultivars confirmed this finding; Mashuri, being the cultivar with the highest competitive ability, was lower yielding than IR8. INTERCOM was used to estimate the trade-off between competitive and yielding ability by quantifying the effect of single traits on both yielding (simulations in weed-free conditions) and competitive ability (simulations in weedy conditions). This approach demonstrated for instance that a more or less identical increase in the ability to suppress weeds could be obtained through an increase in either specific leaf area or light extinction coefficient. Under weed-free conditions, grain yield responded quite different to an increase in one of those traits. An increase in light extinction coefficient caused a poor light penetration and poor distribution of radiation within the canopy, resulting in a reduced radiation-use efficiency and accordingly in a decrease in simulated grain yield. An increase in SLA on the other hand, led to earlier canopy closer and accordingly to an increase in simulated grain yield. This example shows that trade-off between competitive and yielding ability differs per trait and moreover that the model is an appropriate tool for designing competitive, high-yielding ideotypes (4).

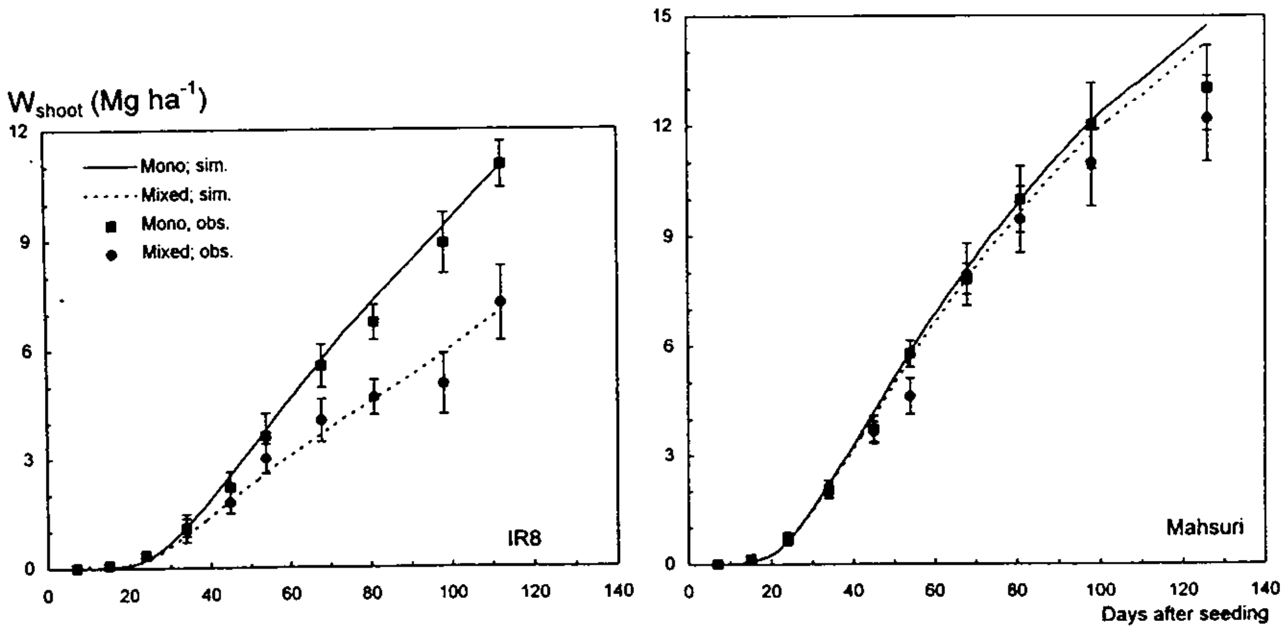


Figure 4. Observed and simulated shoot dry weight ($W_{shoot}$) of rice in monoculture or in mixture with purple rice for IR8 and Mahsuri rice. Vertical bars represent the standard errors of the mean. (4)

*Weed population dynamics*: The life cycle of annual weeds is schematically illustrated in Fig. 5. The main processes are germination and emergence of seedlings from seeds in the seed bank in the soil, establishment and growth of the weed plants, seed production, seed shedding, dispersal, predation and seed mortality in the soil. Competition plays a major role in different stages of the life cycle and therefore strongly affects the population dynamics of weeds. For perennial weeds or clonal weed species, additional processes of importance are regrowth from buds on underground structures and the formation of these structures. The dissemination, invasion and spread of weeds is not indicated in the scheme, but is of extreme relevance for the population dynamics of weeds in real farming systems. Besides natural processes of spread, the spread of weed seeds by farmers' equipment is of great significance as well.

Models can be helpful to integrate the knowledge on life-cycle processes. The most detailed models that encompass the whole life-cycle have been developed for species like *Avena fatua* L. (7), *Alopecurus myosuroides* Huds. (12) and *Galium aparine* L. (41). Comprehensive models that are based on physiological principles are only available for parts of the life cycle: plant growth and competition (19) and germination and emergence (42). In contrast, processes like seed shedding, seed dispersal and predation of seeds are poorly understood.

The basic structure used in most models was described by Spitters (39) and Kropff et al. (24). In this model, the density of weed seeds in the soil is indicated by $S_t$, where the subscript denotes the year when density is observed. Each year a portion $m$ of the seeds is removed by natural mortality of seeds, and a portion $g$ is removed by germination and emergence of seeds. The emerged plants will reproduce on average $z$ viable seeds that return to the seed bank. The effect of weed plant density on $z$ is introduced by a rectangular hyperbola:

$$z = \frac{a}{1+\frac{a}{b}g(1-r)S_t} \qquad (3)$$

where $a$ is the production of viable seeds per plant at low weed densities and $b$ is the maximum seed production per unit area at high weed densities. Weed control is introduced by multiplying the density of emerged weeds by $(1-r)$, where $r$ is the fraction of weed seedlings killed by weed control. Integration of these life-cycle processes into one equation that generates the weed population dynamics in terms of density of weeds in the soil gives (24):

$$S_{t+1} = (1-g-m)S_t + z(1-r)gS_t \qquad (4)$$

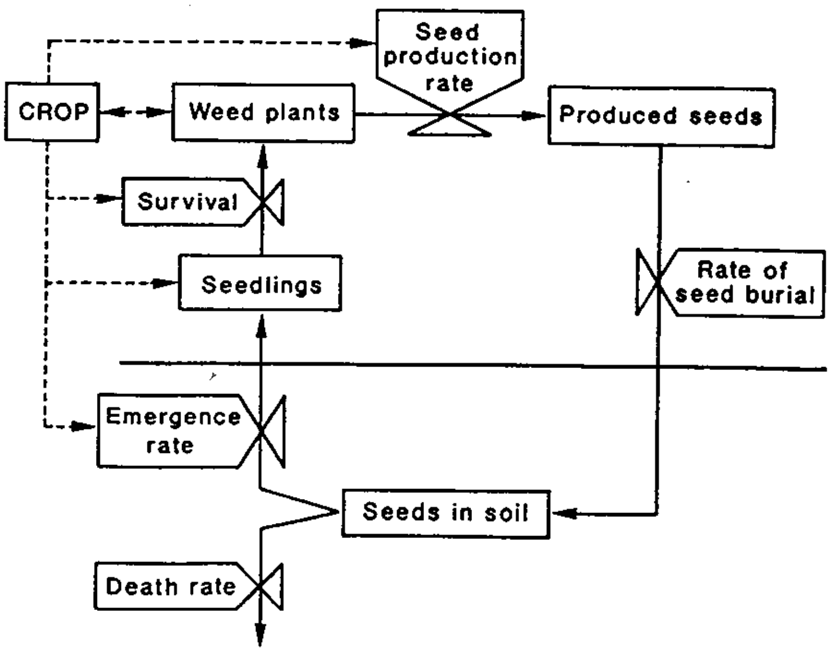


Figure 5. Schematic representation of population dynamics of weeds. Drawn lines indicate the life cycle of weeds, broken lines indicate processes where crop and weed interact (19).

This equation shows how the density of seeds in the soil depends on the density in the previous year, on the population dynamic characteristics of the species, and on the intensity of weed control. In this simple case the model can be written as one equation and solved analytically, but when processes are described in more detail, numerical integration techniques have to be used. Since density of weeds is taken as a key variable, these models are generally referred to as density based models. Due to the conceptual clarity in modelling temporal changes in density this approach is widely used, ranging from exponential growth (36) to bounded growth (13).

The major difference between population dynamics of weeds and other plants is that man explicitly interferes in weed population dynamics. Models for *weed* population dynamics thus have a control variable as an additional parameter ($r$ in equation 4), whereas models of plant population dynamics do not. The aim for weed population dynamics models is to find the optimal control strategy that fits the needs of the farmer. The simplest way of using density based models for this purpose is to conduct scenario studies based on different control strategies. Such a simple approach helps to get a better notion of the consequences of various weed control strategies and to roughly explore options for long term weed management strategies. Some examples are given below.

*Required seed-cleaning efficiency*: Firbank & Watkinson (13) determined the effect of different weed control efficiencies on the long-term, or equilibrium weed density. Their results showed that the sensitivity of long-term density towards differences in control efficiency was strongly related to the level of control efficiency. In their model-system corncockle (*Agrostemma githago* L.) in spring wheat (*Triticum aestivum* L.) contaminated wheat seed was regarded as the only source of weed infestation and seed cleaning as the most important control strategy. Model calculations demonstrated that a seed-cleaning efficiency of less than 50% would hardly influence the long-term density. Efficiencies between 50-80% had a marginal effect, whereas an improvement in cleaning efficiency between 80-90% had a strong effect on the long-term weed density. Eradication would occur if cleaning efficiency would exceed 90%. These results demonstrate that the significance of an improvement in weed control technique is among others related to actual control efficiency.

*Increased crop competitive ability for management of weed populations*: Kropff *et al.* (25) used the model of Firbank & Watkinson (13) to determine whether the introduction of spring wheat cultivars with an increased competitive ability would reduce the seed production of *A. githago* and thus lower the need for high seed cleaning efficiencies. In a preliminary analysis it was found that the seed cleaning efficiency required to maintain the population of weeds at a low density (the critical seed cleaning efficiency) only decreased strongly when the reduction in *Agrostemma* biomass as a result of competition by the crop exceeded 60%. This means that an increased competitive ability only affects long term population development effectively when weeds are suppressed strongly. With the previously discussed example of rice it was shown that large differences in competitive ability between genotypes of cereals are present (4).

*Frequency of herbicide-application*: Spitters (39) used a similar model to determine the frequency of herbicide-application required to manage wild oat in continuously grown spring barley. For this purpose the population dynamical model was coupled to a simple descriptive model for yield loss. Calculations were based on a control efficiency of 95%, established through a post-emergence application of a herbicide. The simulations demonstrated that weeding wild oat once every second year restricted yield losses to about 5% or less. Such a control strategy would be economically attractive, since in cereals yield benefits of less than 5% in general do not outweigh the costs of herbicide application. The only disadvantage of this control strategy would be that a failure of weed control in one year bears the danger of having to take cumbersome and more expensive measures against large infestations in future crops. With annual control of wild oat in cereals a farmer would restrict the increase in weed seed population, avoiding the risk of serious weed problems in future crops. In this example the model thus helps to identify the consequences of various control strategies, offering farmers the opportunity to select the strategy that fits their attitude against risk. This analysis refers to situations were cereals are grown continuously. For cereals grown in rotation with other crops the situation is different, since weeds are often controlled in cereals to reduce problems in future crops, as cereals offer good opportunities for weed control.

*Usefulness of damage thresholds*: Wallinga and van Oijen (46) used the density based model to determine the influence of the threshold level on the frequency of herbicide applications. In a simulation study based on their analysis, threshold levels of 2 and 40 seeds per $m^2$ were imposed (24). A control measure was applied for densities above the threshold, whereas below the threshold weeds were left uncontrolled. The simulations resulted in an oscillation of weed density in a periodic fashion around the threshold, with a frequency that seemed to be independent on the threshold value. This result suggests that long-term application of a control threshold results in a control frequency that is independent of the threshold level. In the more detailed analysis, Wallinga and van Oijen (46) reached a similar outcome and concluded that the weed control threshold as a tool to base control frequency on economic considerations loses meaning when it is applied to the long term.

*Extensions of the density based approach*: The previous examples all deal with a continuously grown single annual crop species and with one weed species that can manifest a rapid population growth and that can cause severe yield losses. In for a continuously grown crop. This does however not cause any essential changes in the approaches outlined above. A few studies have been directed at modelling population dynamics over crop rotations (e.g. 27, 31). Several studies have tried to get a grip on the problem of multiple weed populations with different characteristics (16, 32). This appears to be very complex.

Another assumption underlying the previously described approach is that each weed perceives a similar environment and that the system is homogeneous in space. However, environments are heterogeneous and population development is heterogeneous, even in a homogeneous environment. A rather obvious way of including dispersal of weeds is to include space into the model and allow for spatial gradients in density, which results in so-called reaction-diffusion models. Discrete versions of this type of models have been employed to simulate spread of weeds (1, 2, 30). The key variable in this modelling approach is the weed density as well. Since density is interpreted as a real variable it is easy to generate artefacts like 0.001 plant on one square meter. This problem can be overcome by truncating low densities to integer values (14, 35). Another problem is that in the course of time spatial gradients will eventually flatten out. Therefore it is hard to explain the observed patchiness of weeds by these models. A different approach is to abandon weed density as a basic variable in the model, and proceed with the actual configuration of weeds over space. This modelling approach includes model types like the individual based model (cf. 33) and cellular automaton models (cf. 3, 37). This type of models makes it possible to study the interaction between dynamics and patchiness in weeds. Wallinga (45) analysed the development of patchiness of weeds at realistic low densities using such an individual based spatial model. This study demonstrated with simulation studies that patchiness occurs naturally at low weed densities, even in homogeneous environments. Of the modelling approaches, individual based models are the most comprehensive, but as a result of their complexity they quickly run into computing problems.

## CONCLUSION

For the development of weed management systems which are effective at minimum cost, safe for the environment and adaptable to individual situations, an integrated weed management approach has to be developed in analogy to the strategies developed for integrated pest management (IPM). Options to improve weed management systems with a minimum herbicide use exist in all its components: prevention, decision making and control technology (Fig. 2). Future research should focus both on technology development as well as on prevention, and operational and strategic decision making. Quantitative insight in weed ecology and crop weed interactions is essential for that purpose and further increase of eco-physiological insight in these processes as well as integration of this knowledge in manageable models should be one of the main targets for future weed ecological research.

By focusing weed biology research on clearly defined problems, weed research might give a major contribution to the development of more sustainable agricultural production systems in the coming decade. Some clearly defined problems where quantitative knowledge on weed biology can be applied seem feasible

(i) The identification of new potential break points in the life cycle of weeds that may lead to the identification of new control technologies. The use of systems approaches can encourage weed ecologists to produce challenging questions for weed technologists. An example is the separation of the effects of weeds in current and future crops. Often weeds do not cause yield loss in a current crop (28). In such situations, we need new technology to avoid or reduce weed seed production. Biological knowledge and insights could be used to develop technologies that enables interference with the development of plants. An idea could be to prevent flowering in short-day plants (weeds) when days become shorter by interrupting the night period using light flashes (19).

(ii) The development of site specific management techniques in which only patches of weeds are controlled. A question here is how intensive weed patterns would have to be sampled to facilitate precision agriculture. The use of spatial statistics has opened perspectives in this area (5, 10), yet such a purely descriptive approach is a far cry from biological understanding of weed patterns. The localised application of herbicides begs the question how population dynamics are affected and what the long-term viability of this technique will be (17). Here, the study of weed dispersal (9) and individual based modelling techniques (44) can be of help to improve weed management

(iii) The development of strategies for weed control based on long term dynamics of weeds. Suitable strategies for weed control will in most cases be containment strategy, which is directed towards managing weed populations, rather than to eradicate. The approach to be used would be to calculate the required weeding efficiency to maintain a low density and how such a weeding efficiency can be realised.

From this list of problems it may be clear that, although ecophysiological research in weed science has concentrated primarily on crop-weed competition and population dynamics with few links to other critical areas like invasion, rate of spread, effectiveness and economics of weed control (11), the future challenge for weed science will be the development and integration of the different components.

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# INNOVATIVE APPROACHES AND FUTURE TRENDS IN HERBICIDE DEVELOPMENT AND USE

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*Summary:* Agrochemical companies including Novartis continuously introduce new innovative products and services which will contribute to development of agriculture. Cost-effectiveness, bio-efficacy, crop selectivity, environmental soundness and applicators' safety are the most important criteria for designing, selecting and developing new active ingredients, safeners, new formulations and packages. Companies discovering and developing new active ingredients, particularly having a new mode of action will remain competitive in the long term. Herbicidal spectrum and crop selectivity, application time, dosage rate, environmental and safety properties and formulation flexibility are key areas for innovation. Integrated weed management (IWM) provides the most cost-effective and environmentally sound solutions by systematically integrating available weed management technologies including herbicides. Areas for further advances of IWM include interdisciplinary cooperation in research, communication with farmers and development of new weed management methods.

*Keywords*: herbicide development, sustainable agriculture, innovative technology,

## INTRODUCTION

Productive agriculture is essential to meet the food and fiber needs of a continuously growing world population. Further improvement in the productivity of arable land is needed to minimize conversion of forests and other natural resources to agriculture (17, 24). Weed control is a major component of productive agriculture. Today, herbicide is a widely practiced technology for weed control and provides agronomic, sociologic and economic benefits to farmers (7, 30). The structure of the herbicide market has been changed by the introduction of new active ingredients (5, 7, 23). In addition, continuous changes in agronomy, technology and economy will surely give rise to "Never Ending Story". In this sense, what I attempt to discuss here is based on personal experiences and discussions with my colleagues inside and outside the company. Some subtopics are discussed using examples in rice (*Oryza sativa* L.), a crop with which I have most direct experience.

## AGRICULTURE AND FARMERS IN THE FUTURE

Since it takes up to 10 years to commercialize a new product from its discovery, it is indispensable for us to understand the factors affecting farmers' business, their objectives and their needs for weed management in a long term perspective. We have to make sure that farmers and their needs occupy the central part of our considerations. Furthermore, we have to realize that farmers are not the same worldwide even if they grow similar crops.

Farmers are responsible for choosing the best suitable practice in weed management for their agronomic situation and for supplying sufficient amounts of agricultural products in a most effective way. Farming practices are being challenged in many areas (16, 17, 19, 24). Key factors we see are;

- Loss of productive agricultural lands and of farming labor resulting from industrialization and urbanization, particularly in the tropics,
- Pressure on price of agricultural products due to the change of subsidy policy and liberalization of world trade,
- Increasing demand for meat, vegetables and fruits particularly in developing countries,
- Increasing public concern about modern agricultural practices and their influences on the environment and human health,
- Soil erosion, glasshouse effect and fluctuating weather (particularly drought or waterlogging).

Farmers will respond to those challenges in the following way (7);

- They will try to produce even more food and fiber in the limited amount of available arable land,
- They will continue to become more educated and more business oriented,
- They themselves will be more environmentally conscientious.

Nowadays, the "sustainability" of agriculture is being widely debated and there are many definitions of "sustainable agriculture" (24). By our definition, sustainable agriculture uses those practices and systems that maintain and enhance 1) sufficient and affordable supplies of high-quality food and fiber, 2) economic viability and 3) the natural resources and the environment. We believe that agriculture in the future will increasingly use "sustainable" practices, of which weed management will be one of the major components.

## HERBICIDE INDUSTRY

The global crop protection industry is facing serious problems such as (7, 10, 29):

- Increased time and cost to discover, develop and register new active ingredients,
- Increased cost to re-register existing active ingredients primarily due to increased regulatory impact,
- Intense competition and strong price pressure as a consequence of political initiatives such as CAP in Europe and PIK in USA and the launching of generic products.

This situation, as well as globalization of the market, will force further consolidation of the crop protection industry (7). On the other hand, this will open a new opportunity for smaller and specialized companies in niche markets such as regional business, biological agents and generics.

Principle trends in herbicide R&D we see today are;

- Introduction of new screening technologies such as "High Throughput Screening" (HTS) in order to improve the chance of discovery of new active ingredients and modes of action,
- Reaction to increasing importance of fodder crops such as corn (*Zea mays* L.) and soybean (*Glycine max* Merr.) to meet increasing demand for meat and poultry products, of tropical crops such as rice to feed increasing population, and of vegetables and fruits to ensure adequate supply of vitamins and micro nutrients,
- Increased emphasis on specific solutions (use recommendation and formulations) to better meet specific regional situations, particularly in the tropics,
- More transparent communication with farmers and the public, as well as politicians, governmental organizations and environment-interest groups,
- Increased effort to internationally harmonize registration requirements and crop residue standards in relation to the liberalization of the world food trade.

## CHANGES IN WEED MANAGEMENT TECHNOLOGY

### 1. Herbicide

Environmental properties, applicator's safety and anti-resistance strategies (17) as well as cost-effectiveness are the most important criteria for designing, selecting and developing new herbicides. Each of them has almost equal importance and we must strive for the right balance.

*New active ingredient*: A new ingredient could offer 1) an entirely new dimension of chemical weed control, 2) a more selective, lower-dosed and/or more environment-friendly solution, 3) a more cost-effective solution, and/or 4) an anti-resistance tool. Many companies are therefore continuously active in searching for new active ingredients. We believe that only companies successful in discovery and development of new active ingredients, particularly having a new mode of action, will remain in the long term (17, 29).

*Herbicidal spectrum and selectivity*: Spectrum and selectivity are the driving factors in the selection process of primary screening. In many cases, a wide herbicidal spectrum is wanted. However, it may be more realistic to set a target to discover an ingredient which selectively controls a group of weeds; for example, 1) grasses and some annual sedges, 2) annual sedges, monocots and dicots, 3) perennial non-grass weeds, and so on. "Physiological selectivity" in crops will be more desired, though not indispensable, in the future. Wet seeded rice is a good example of such a crop. It demands a very high degree of physiological selectivity because rice seed exists at the soil surface and consequently "position selectivity" cannot work.

*Application time*: There is a tendency to shift the application time from mere pre-emergence (PRE) to post-emergence (POST) in almost every key crop. It is, however, not very practical to rely only on pure POST herbicide in all situations; for example, in those crops demanding good weed control at a very early stage or where accurate POST application is difficult due to labor or weather problems (30). From this respect, early post-emergence (or combination of POST and residual PRE activity) would be the best time for herbicide application in seeded and transplanted rice in monsoon areas.

*Dosage rate*: In general a lower dosage rate may allow lower production cost, increased environmental friendless and formulation flexibility. It would be wrong, however, to focus exclusively on the dosage rate while neglecting such important characteristics as the leaching potential and degradation pattern in the soil which could partially or fully offset the benefits from a low use rate (30).

*Environmental and safety properties*: Only environmentally favorable ingredients which have a high safety to humans and wildlife will remain in the future. Such environmental parameters as soil degradation, leaching and activity on non-target crops are also essential and must be evaluated in the primary screening.

*Formulation flexibility*: Formulation flexibility and compatibility with other active ingredients will be increasingly important criteria in the characterization process.

The primary screening system using intact plants has been the backbone of lead discovery and optimization of new active ingredients in the herbicide industry (21). "High Throughput Screening" (HTS) is one of several options for attempting to improve the success rate and will play an increasing role in future discovery strategies. However, there are critical technical and practical hurdles to overcome before realization of HTS. They include selection of bioassay methods (for example, enzyme-based or cell-based method), automation in processes of chemical synthesis and bioassay, and data storage and retrieval.

*Safener*: Safeners are chemical tools to expand the use of existing active ingredients (marketed or under development) from the industry's R&D viewpoints (15). Fenclorim (CGA123407) (4,6-dichloro-2-phenylpyrimidine) is the first rice safener that allows the use of pretilachlor [2-chloro-2', 6'-diethyl-N-(2-propoxyethyl) acetanilide] in wet seeded rice (26). Another aspect of the safener is for the control of weeds which are too botanically close to the crop. An example of such a weed is shattercane (*Sorghum bicolor* L.) in sorghum (*Sorghum* spp.). Fluxoferim (CGA133205) [*O*-(1,3-dioxolan-2-yl)-2,2,2-trifluoro-4'-chloroaceto-phenone-oxime] applied by seed treatment makes it possible to selectively use metolachlor [2-chloro-2'-ethyl-N-(2-methoxy-1-methylethyl)-6'-methylacetanilide] to control shattercane and other grass weeds in grain sorghum (6).

*New formulation*: Formulation technology has been and will play a very important role in product innovation in herbicide technology. The aim will be improving handling convenience, reducing transporting/storing cost, improving applicator's safety, reducing problems of waste (used container), and/or reducing application labor. Principle changes in herbicide formulations we see today are as below;

- Less use of organic solvent in liquid formulations by shifting from EC to SC or EW,
- Increase of less bulky formulations by increasing concentration of active ingredient(s) or by a shift from powder (WP, SP) to granules (WG, SG),
- A shift from liquid (EC, SC) to dry (WG, SG) formulation for reduced use of glass/plastic bottles.

In Japan, new formulation types have been or are being developed for "from-dike" application in transplanted rice (Table 1, adapted from 12). Expensive and time consuming labor in the paddy field can be reduced by application from the dike. In case of the "Jumbo" formulation, the formulated product applied from the dike (100-200 spots $ha^{-1}$) spreads and distribute evenly with help of movement of standing water (= a positive aspect of standing water) and spreading agents in the formulation.

Table 1 : New formulation types for "from-dike" application in transplanted rice in Japan

| Formulation type | Application method | | Rate $ha^{-1}$ | Necessary equipment |
|---|---|---|---|---|
| SC | From-dike | Bottle-sprinkle | 5L | None |
| WG | | | 0.5-1.0 kg to apply at 5L water | Refill bottle |
| | | "Shooting" | | "Water gun" |
| Self-spreading GR | | Throw-in/band | 5-10 kg | None |
| "Jumbo" | | Throw-in/spot | 100-200 "Jumbos" 0.5-1.0 kg | None |
| GR (conventional) | Walk-in-paddy | Broadcast | 10 kg | Broadcaster |
| EC (conventional) | | Bottle-sprinkle | 5L | None |

*New Packaging*: The packaging of product can also be developed to improve operator's safety and/or to reduce waste (used container). The "Water-soluble bag" (W.S.B.) is an example of such a technology which ensures that the operator has no contact with the formulated herbicide (22, 30). Another example from Novartis is the "Farm-pak", a refillable liquid container which can be returned for recycling after consuming the herbicide (30).

*New mixture*: The use of mixtures, either ready-made or tank-mix, will be increased to fulfill activity gaps of straight active ingredients, to adapt to specific regional situations, to manage shift of weed flora and/or to manage development of weed resistance to herbicides. In Japan, intensive effort has been made to reduce numbers of application per crop, from serial application of herbicides to so-called "one-shot" mixtures (5, 18).

*Application equipment*: To ensure bio-availability of a herbicide to weeds and minimize its effects on non-target areas, it should be applied and delivered effectively to the targeted weed and/or soil. On top of the effective application, such factors as operator's safety, labor-saving and equipment cost (particularly in developing counties) should be considered when designing and selecting application equipment. Thus, application technologies for herbicides will receive much more attention in herbicide development and its use even than today. Key areas for innovation would be;

- Targeted application by computerized application equipment,
- Drift management by such spraying systems as shielded spray boom, air-assisted spraying and electrostatic charging (22)
- Cost of equipment for farmers in developing countries; such as low-volume sprayers driven by solar-battery and "water-gun" applicators for paddy rice uses.

2. HTC (herbicide tolerant crop)

HTC can be obtained by genetic engineering (gene transfer) or conventional breeding. HTC provides farmers with an additional tool in weed management which could be more flexible and cost-effective (4, 8, 25). HTC also provides the industry with an opportunity for expanding the use of existing active ingredients. Non-selective post-emergence herbicides having a wide herbicidal spectrum are commonly selected for research and development of HTC. In fact, genetic-engineered HTC for glyphosate [N-(phosphono-methyl)glycine] and glufosinate {DL-2-amino-4-[hydroxy (methyl) phosphoryl] butyric acid} are already available in corn, soybean and oilseed rape (*Brassica* spp).

Several concerns, however, about HTC have been expressed and this can create problems in registration for practical use in some countries (1, 4, 25). Those concerns include ;

- Repeated use of a specific herbicide will accelerate the selection of resistant weed,
- HTC may itself become a weed problem particularly in crop-rotation situations (e.g., "volunteer" corn in a succeeding crop like soybean),
- Gene will "escape" and be transferred to related weed species and create more problems,
- High level of tolerance will encourage more use of herbicide,
- Farmers will be entirely dependent on the seed-herbicide package offered by big companies,
- Safety of "exotic" protein to humans.

However, the benefits of HTC have been demonstrated (8, 25) and HTC-technology can offer potentially interesting additional tools for weed management.

3. Biological weed control and mycoherbicides as a non-chemical solution

Biological weed control is the deliberate utilization of natural enemies of specific weed(s) and includes both macro-organisms (insects, mites and nematodes) and micro-organisms (viruses, bacteria and fungi) (2, 20, 28). Among them, fungi are believed to have the greatest potential as commercial bio-control agents for weed management (20). Viruses and bacteria could be utilized only in a very specific situation because of the necessity for a wound to facilitate entry into the plant: a bacterium *Xanthomonas campestris* is being developed in Japan for control of annual bluegrass (*Poa annua* L.) in putting greens of golf courses where mowing is frequently practiced (11). Four mycoherbicides have been registered worldwide (2, 20, 28); DeVine™ based on *Phytophthora palmivora* for control of *Morrenia odorata* in Florida's citrus orchards, Collego™ based on *Colletotrichum gloesporioides* for control of *Aeschynomene virginica* on rice and soybean in Arkansas, USA, BioMal™ based on *Colletotrichum gloesporioides* for control of *Malva pusilla* on wheat in Canada and Luboa™ II based on *Colletotrichum gloesporioides* for control of *Cuscuta* spp. on soybean in China.

Although there are many opportunities for mycoherbicides, it is very unlikely that they will replace traditional herbicides because of the following constraints (2, 20) :

- Small market potential per product as a result of;
  - High host-specificity (i.e., very narrow herbicidal spectrum),
  - High dependence on such environmental parameters as temperature and dew requirement for good and stable weed control,
- Relatively high investment required for technology development of mass fermentation (or production), formulation and delivery system to customers,
- Varying guidelines for field testing and for establishing toxicological and environmental profiles,
- High uncertainty about patent protection.

In brief, only very low development costs and short development time could make mycoherbicides attractive for the industry. Uniform registration guidelines and focused efforts on key weed targets will be necessary to make mycoherbicides a reality (20).

4. IWM (integrated weed management)

The practice of systematic integration of available weed control technologies including herbicides (IWM) provides the most cost-effective and environmentally sound solutions for weed management. There are many research works on IWM (27) including ones by Novartis (9, 13, 14, 31); There is still, however, clearly room for further advances. Firstly, there is a need for interdisciplinary cooperation in IWM research because areas involved are wide-ranged and complex. Those areas include tillage system, critical period of weed interference, alternative methods of weed control such as cover crops, cultivation, herbicides and biological weed control agents, crop competitiveness, modeling of crop-weed interference, crop rotation and seed bank dynamics (27). Secondly, farmers generally choose weed control methods based mainly on economics and effectiveness (19). This necessitates more effective communication with farmers about IWM benefits.

Traditional rice farmers in Asia can be proud that IWM has been practiced in transplanted rice for a long time by integrating many weed management components such as repeated puddling practices at a certain interval to allow weeds to emerge and to mechanically control them, transplanting itself to give competitive advantage to the crop, water management practice as well as more recently herbicides. The rice cropping system, however, has been shifting to direct seeding in many areas of tropical Asia and this has resulted in new weed problems (3, 16). In addition, there is an increasing concern about potential effects of herbicide uses on the environment and health of farmers and farm residents (16, 19). Since rice is a crop of particular importance in the region, it is necessary for all to actively work on IWM in direct seeded rice.

5. Information technology (IT)

*Services to customers*: Farmers are becoming more educated and more business oriented and this will force the industry to change their promotion style from mass-media approaches to "relationship marketing" (7) and from the mere product-oriented to the knowledge-oriented (24). The advance in IT (computer and related technologies) will help the industry improve the quality of services to customers. For example, computer-based decision-making-support system could offer;

- Analysis and decision-making subsystem based on IWM research work (see above),
- Real-time capture subsystem of meteorological data,
- Precise and transparent data-bases on herbicides,
- Input subsystem for user-specific agronomic data

In addition, the industry will put more effort on close and transparent communication through on-line network (e.g., internet or LAN) with farmers and the public.

*As a tool for R&D*: IT will play an increasing role within R&D for capture, storage and analysis of biological data.

## CONCLUSION

New technologies in weed management should and will be more environmentally sound, be safer to humans and wildlife, provide better weed control and/or crop selectivity and/or be more cost-effective than the currently available solutions. They will, therefore, contribute to development and implementation of practices and systems used for sustainable agriculture.

Farmers are responsible for choosing the best suitable practice in weed management for their agronomic situation and for supplying sufficient amount of agricultural products at a reasonable cost and profit. Any new innovations should be more beneficial to them than currently available solutions. We, therefore, have to make sure those farmers and their needs occupy the central part of our considerations. To ensure this, we need to better communicate with farmers. In addition, transparency and quality of communication with governmental bodies, research institutes, registration authorities, extension workers, consultants, wholesalers and retailers should be improved. International harmonization of registration systems and requirements and crop residue standards will also contribute to development of innovations and thus the development of sustainable agriculture.

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# WEED MANAGEMENT STRATEGIES FOR PRODUCTIVITY INCREASE IN LOW-INPUT FARMING SYSTEMS

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*Summary.* A majority of farmers in the developing countries of the world are involved in low-input agriculture. Weeds and their management have preoccupied these farmers for decades. In spite of this, weed management practices in low-input farming systems have not significantly changed over the years, partly because of the low resource base of farmers in these farming systems, and partly because of the diversity in low-input agriculture in general. This diversity is evident among farming households in the same village, between villages, in soil, and in the cropping systems used by the farmers. The differences are also reflected in such other ways as farm sizes, ownership and distribution of production factors. Consequently, crop yields vary from one household to the other, and from one farming system to the other. Weed management strategies for productivity increase in these low-input systems should be such as will minimize variability in crop production environments and maintain land productivity. The challenge to weed scientists world-wide is to develop appropriate weed management technologies that will reduce soil degradation, reduce the drudgery associated with food production, and increase productivity in low-input farming systems. This paper discusses four weed management models that involve management of the crop-weed habitat, and have potentials to increase productivity in low-input farming systems.

*Keywords*: farming systems, low-input agriculture, management strategies.

## INTRODUCTION

Low-input farming systems occur mainly in the developing countries of the world, and these in turn are mostly found within the warm tropics. There are currently 137 countries known as developing countries and they include 72 that are known as low income food-deficit countries (Table 1).

Table 1. Food import bills of developing and low income food-deficit countries (LIFDCs) past and present[1].

| Region | No of countries | Actual (1987-89) | Projected (2000) | Size of increase |
|---|---|---|---|---|
| | | (US $ billions) | | |
| WORLD | | | | |
| All developing | 137 | 40.0 | 64.7 | 24.7 |
| LIFDC | 72 | 17.8 | 27.6 | 9.8 |
| AFRICA | | | | |
| All developing | 52 | 6.0 | 10.5 | 4.5 |
| LIFDC | 43 | 3.5 | 6.3 | 2.8 |
| LATIN AMERICA | | | | |
| All developing | 46 | 8.0 | 12.7 | 4.7 |
| LIFDC | 10 | 1.6 | 2.4 | 0.8 |
| NEAR EAST | | | | |
| All developing | 19 | 11.5 | 16.8 | 5.3 |
| LIFDC | 6 | 3.7 | 4.7 | 1.0 |
| FAR EAST | | | | |
| All developing | 20 | 14.5 | 24.7 | 10.2 |
| LIFDC | 13 | 9.0 | 14.2 | 5.2 |

[1](8).

Farmers in many low-input farming systems appear to conjure an image of people living in parts of the world where they could have made progress if there were adequate infusion of capital and technical knowledge into their agriculture.

Coincidentally, agricultural pests, particularly weeds, grow and multiply profusely in the low-input farming systems because of favorable environmental conditions. Consequently, weeds readily choke cultivated plants and reduce crop yields despite heavy investment in farmers' time. By contrast, farmers in high-input farming systems of most developed countries appear to have come to terms with crop pests with the aid of modern technologies. The challenge is how to free weed management in low-input agriculture from drudgery.

Weed control in high input agriculture of developed countries is no longer a human struggle with weeds but one in which modern development in chemical weed control, use of mycoherbicides and transgenic crops have combined to remove drudgery from farming and reduce losses caused by weeds in agriculture. Are these technologies appropriate to low-input farming systems? The chances are that they are not. Richards (16) had cautioned against the temptation of always trying to solve problems of low-input agriculture by importation of what, at face value, look like 'appropriate' agricultural inputs from the high input and advanced agricultural systems. After years of experience coupled with failures, it is now widely accepted that there is need to understand the ecological and socio-cultural environments of specific low-input agricultural systems in order to develop weed management systems that will be appropriate for increased productivity in these low-input systems. Zimdahl (21) noted that the public image of weed science is a concern and a source of frustration and discouragement to people in developed countries. In the low-input farming systems of developing countries, weed scientists are so few and their impact on agriculture of the region is so small that the public seldom knows that weed control, traditionally relegated to women and children, can be considered as a science.

## PROBLEMS

Weed management among low-input farmers is beset with problems, some of which are associated with low resource base among these farmers. These problems limit the range of technologies that farmers can choose from. Limits imposed on available arable land by human population pressure force farmers to cultivate the same land intensively and this leads to both land degradation and increased weed infestation. The primary reason given by farmers for large family sizes is to have the labor for weeding and related activities. This increased population in turn leads to the type of pressure on land that causes land degradation. When weed infestation increases, farmers respond to it by increasing weeding frequency.

Appropriate weed management for low-input production systems is generally lacking. Weed management technologies that have been most popular world-wide are economical at operational scales that are far beyond the scope of low-input farmers. Prospects for improved weed management in the developing countries must include innovations that will make weeding attractive, less labor-intensive, and contribute to keeping the entire food production enterprise economical, safe and on a sustainable yield basis. There is a need for an ecosystem approach to weed management in low-input agricultural systems. Such an approach will take into consideration the interactions between the natural resources, the human needs, and farmers perception of production environments. There appears to be an absence of an enabling environment that will bring about workable integrated weed management (IWM) technologies that will be specific for low-input production systems. For example, industrialized countries hardly see any future in investing in low-input production systems, and there is a lack of will power on the part of governments and people in countries dominated by low-input agriculture to work together to improve on traditional weed management practices.

Smallholder farmers in low-input agricultural systems now have serious weed problems on their farms because improvements in other sectors of the human enterprise have put such pressures on the limited arable land that their food production needs can no longer keep pace with the natural rate of soil fertility maintenance. Consequently, good arable land on which food is produced has become heavily infested with weeds, impoverished through overuse, and scarce because of increasing human population pressure. Traditional methods of weed control are no longer appropriate for dealing with weed problems, and urban migration has made labor scarce and expensive. Progress in weed management in low-input agriculture should see movement away from human labor, as the primary source of energy for weed removal, to alternative weed control technologies. The objective of this paper is to review weed management strategies that will increase productivity on a sustained yield basis in low-input farming systems.

## CONSTRAINTS TO DEVELOPMENT AND TESTING OF LOW-INPUT WEED MANAGEMENT TECHNOLOGIES

Weed control practices have not changed significantly in many of the countries with low-input agriculture in the last 25 years despite the fact that more people have been trained in weed science, more research activities have been initiated in these parts of the world, and there has been greater awareness of weed problems than in the past. Hand weeding either by pulling weeds off or by hoe weeding still dominates the agriculture of low-input farmers in these countries. There are very few improved weed control technologies that have reached the on-farm level of testing to date mainly because there is either nobody to carry out the field tests or no logistic support for them. In spite of what has been said or written to date, hardly any improved method of weed control has been packaged and field-tested to meet the special needs of low-input farmers. Development of IWM technologies has to be done within the context of the production circumstances in which farmers carry out their farming activities. There is often a lack of a reference point to assess the weed problems of farmers in low-input agricultural systems. Many weed scientists fail to appreciate the problems of low-input agriculture. Consequently, farmers' perceptions of what technologies will be appropriate to their farming circumstances are often overlooked or taken for granted by weed science researchers, especially if field tests show that the tested technologies make economic sense. Therefore it is important that potential IWM for low-input farming systems take farmers' perceptions about new technologies into consideration before these technologies are given to them.

The average farmer in a developing country has little or no resources and therefore can neither afford to take big risks nor go for technologies that require a lot of external inputs. A proper assessment of the prospects for IWM in low-input farming systems should take stock of where farming in these countries has come from, where it is now and where it is going. Table 2 summarizes the features of past and present production environment of smallholder farmers in most developing countries.

Table 2. Features of selected low-input farming in developing countries[1]

| Parameters | Past | Present |
|---|---|---|
| Household population: | Large; many wives and children. | Large: one wife +≥ 5 children. |
| Dwelling place: | Mud house with thatched roof or other home-made materials needing periodic replacement or frequent repairs. | Few mud houses, many homes built with durable materials brick or cement blocks and corrugated tin roofs. |
| Garden plots and compound farms: | Permanent cultivation with vegetables and economic tree crops. | Small gardens overcrowded with multi-storey crop. |
| Outlying arable fields: | Arable crops; cultivation alternating with long fallow period >7 years. | Arable crops; continuous cropping or short duration bush fallow period of <2 years. |
| Demography: | Large hectare/farmer ratio (>1.5). | Small hectare/farmer ratio (<1.0). |
| Crop yield: | Adequate to meet family needs | Inadequate to meet family needs. |
| Sustainability: | Sustainable | Not sustainable. |
| Weed problems: | Little to moderate | Severe. |
| Weed type: | Mostly annual broadleaves. | Perennial weeds especially grasses, sedges and parasitic weeds. |
| Type of inputs: | High for land clearing but low for weeding. | Low for land clearing but high for weeding |

[1]Source: (4)

A recent study in northern Cameroon shows that there is a lot of diversity in soil and in cropping systems between villages and among households within the same village (7). These differences are evident in many ways, including ownership and distribution of production factors (Table 3). This study also reveals that there was uneven distribution of factors of production among farming households within a village, and that crop yields were consistently variable over time within the village (Table 4). These results have implication for introduction of improved weed management. In order to minimize variability, extension economists have advocated the use of recommendation domains. Even the recommendation domains that were selected in the past for their homogeneity have been shown to be heterogeneous. Designers of weed management technologies have to define their representative sites for reproducible on-farm tests in low-input farming systems. They then have to develop technologies that will be applicable to their clients. The introduction of a specific weed control technology therefore should take into consideration the type of farmers within a given community that will best benefit from the introduced technology.

Table 3. Distribution of means of production as affected by resource base among households in Gaban village, northern Cameroon[1]

| Means of production | Low-resource household (n=13) | High resource household (n=18) | 2-tailed significance level |
|---|---|---|---|
| Family size: | | | |
| Consumers | 5.5 | 9.7 | <0.01 |
| Workers | 3.4 | 5.8 | <0.01 |
| Means of Production: | | | |
| Ox-drawn plows | 0.0 | 1.3 | <0.001 |
| Donkey-drawn plows | 0.2 | 0.6 | - |
| Ox-drawn carts | 0.0 | 0.4 | <0.005 |
| Oxen | 0.1 | 2.7 | <0.001 |
| Donkeys | 0.3 | 0.5 | - |
| Sheep and goats | 2.8 | 12.9 | <0.001 |
| Estimated available amount of manure (kg) | 300 | 3700 | <0.001 |

[1](7)

Table 4. Yield variation in rainfed sorghum in the village of Gaban, northern Cameroon[1]

| Year | Number of fields | Yield (kg/ha)[2] Mean | Minimum | Maximum | c.v. (%) |
|---|---|---|---|---|---|
| 1991 | 44 | 1900 | 500 | 4300 | 52 |
| 1992 | 137 | 2500 | 200 | 5500 | 51 |
| 1993 | 40 | 1600 | 300 | 3200 | 47 |

[1](7).

High landuse intensity has created declining soil fertility problems of such magnitude for farmers in low-input production systems that any effort at sustainable food production must take soil fertility maintenance into serious consideration. Farmers in low-input agricultural systems who generally cannot afford to invest in inorganic fertilizers have to find alternatives to earlier practices of planting on virgin land in order to get high crop yields (6). Weed management practices that contribute to soil fertility maintenance will contribute to reversing the declining yield currently associated with low-input agriculture.

## WEED MANAGEMENT IN LOW-INPUT AGRICULTURAL SYSTEMS

The need for appropriate weed control for tropical agriculture has been a constant concern for weed scientists in many parts of the world for many years. Within the past two decades, symposia and workshops have been organized in different regions and subregions of the world to address this problem. Recently, the FAO and CAB International jointly organized a workshop to address this problem in the Asian Pacific region (15). Labrada *et al.* (12) and Labrada (13) have reviewed the subject extensively with particular emphasis on the role of FAO in promoting improved weed management in the developing countries. According to a recent survey of the status of weed management in developing countries, only four countries have attained 'a high standard of weed management in Asia' (13).

Lack of well-trained weed scientists and limited funding for research and extension were listed as the major constraints to poor development of weed management in developing countries. In spite of the attention that has been given to weeds and their control in the tropics, no major breakthrough in methods of weed control at the smallholder farmer level has really occurred. Hand weeding either by pulling weeds off or by hoe weeding still dominates the agriculture of low-input farmers of developing countries. There are very few improved weed control technologies that have reached the on-farm level of testing to date mainly because there is either nobody to carry out the field tests or no logistic support to carry them out. In spite of what has been said or written to date, hardly any improved method of weed control has been packaged and field-tested to meet the special needs of smallholder farmers.

Weed problems of low-input agriculture is compounded by the low resource base of farmers and the fact that there are so few weed control technologies whose economics of use are based on the farm sizes of these farmers. In order for weed management practices that are developed for low-input agriculture to have wide application, they should at least be based on principles that have wide application. Examples of these principles are those that exploit the allelochemical properties of crop plants as has been reported for rice (15); biocontrol of weeds (11); and the potential use of mycoherbicides (5, 14).

## TYPES OF WEED MANAGEMENT STRATEGIES FOR INCREASED PRODUCTIVITY IN LOW-INPUT SYSTEMS

There are many weed control tools available worldwide but not all of them have potential for the type of weed control that will also increase productivity at low-input farming systems. The biggest challenge facing weed scientists is developing weed management strategies that will minimize drudgery and increase productivity in low-input agriculture. The answers to this challenge are beyond the scope of this paper. If this paper can sensitize weed scientists and the public at large to the need to invest human and material resources to the development of weed management technologies that will increase productivity, then I will consider part of my mission as accomplished. Because land holding is small and the resource base is low, appropriate weed control technologies that can be cost effective in low-input farming systems are hard to come by. Very few weed management technologies have been developed to overcome drudgery associated with food production at the small input farmer level in the tropics. This is because weed science training in high-input agricultural settings have used totally different yard sticks to measure success and failure of technologies, as well as farmer acceptance of these technologies.

In spite of the gloomy picture presented above, there are indications that many traditional and low-input production systems have ecologically sound basis for their use by farmers. For example, mixed cropping systems that were in the past considered primitive have now been seen as having merits and built-in risk aversion techniques. They have also been recognized as appropriate for smallholder farming in the tropics where levels of inputs are low. In many instances where scientists have had the patience to understand the principles on which these smallholder farmers base their practices, these production practices have been seen to provide important conceptual framework for small scale production systems. Low-input agriculture needs to maintain productivity at such high level as to make up for the limited cash flow capacity of farmers, and for the high human population that these low-input systems are now forced to support. One conspicuous feature of the pressure on land is an increased landuse intensity with its attendant high weed pressure. Farmers in these systems lack the capacity to deal with the type of weed seed rain that follows crop harvests and the short fallow period that is associated with areas with high population densities.

Smallholder farmers have for centuries been hand weeding their fields and yearning for alternatives to hand weeding. Cultural weed control has been reviewed repeatedly, including a recent review by Shenk (18) but the plight of smallholder farmers in developing countries has not changed significantly. This has happened because weed scientists have approached weed problems of developing countries using imported weed control technologies that are not fully applicable to the low-input production systems that dominate agriculture in the tropics. Single pest issue approach that has worked well in developed countries and for insect control may not always be the way to deal with weeds of multiple crop systems where years of cultivation alternate with periods of bush fallow. In order to develop weed management technologies for the low-input farming systems of developing countries, there is need to fully understand the agroecological conditions and circumstances responsible for the transformation of tropical vegetation from a resource to an agricultural pest (weeds). Multi-storey crop architecture is common in most smallholder farms and these complex systems have been deliberately adopted by farmers as part of risk aversion measures. It is against this background that we should examine the development of IWM technologies for increased food production in low-input systems in developing countries.

Vegetation is one of the renewable natural resources in agriculture. Therefore agricultural activities that interfere with the maintenance of natural vegetation are likely to interfere with soil fertility maintenance. Weed management strategies that have the greatest potential for maintaining productivity at the low-input farming systems include those that mimic the natural vegetation and should provide ground cover, return organic matter to soil, maintain favorable soil microenvironment for both soil flora and fauna, maintain soil tilth, and minimize weed competition with crops. Some weed management strategies that can meet the above conditions have been reviewed (3). They represent important options for low-input agricultural systems. The underlying principles of these weed management strategies should be field-tested and adapted to meet the needs of specific low-input production systems. The four weed management models are based on the principle that weed control practices that will increase productivity in low-input agriculture must also prevent soil degradation, promote soil fertility increase, reduce the population of weed seeds in the seedbank, and minimize weed competition. The direction to go in order for weed management technologies to remain relevant to low-input agricultural systems is to ensure that IWM fits into crop production packages that inevitably include soil fertility maintenance and use of improved crop husbandry practices This certainly calls for creativity and coping with the reality of the farming environment of smallholder agriculture in which lack of credit, poorly functioning extension services and other infra-structural limitations are common features. Major weed management strategies and their suitability for low-input farming systems are summarized in Table 5.

Table 5. Assessment of major weed management strategies and their suitability for smallholder agriculture in developing countries[1]

| Weed management type | Appropriateness | Effectiveness | Sustainability |
|---|---|---|---|
| Hand weeding | + | ++ | + |
| Chemical weed control | + | ++ | + |
| Habitat management | ++ | ++ | +++ |
| Biological control (mycoherbicides) | ++ | ++ | ++ |
| Integrated weed management (IWM) | +++ | +++ | +++ |

[1](4); + = moderate, +++ = high

Some tools such as habitat management and use of mycoherbicides look promising but their potentials can only be fully realized when they are tested under field conditions. Habitat management which involves modification of the crop/weed microenvironment to favor the crop as illustrated in live mulch studies (1, 3) have proved effective in researcher-managed conditions. They appear appropriate for the fragile tropical environments where farmers most farmers produce their crops at low-input levels. These environments in which most developing countries of the world carry out their crop production enterprises make habitat management and IWM not only desirable but a requirement for sustainable food production. The efficient and economical use of resources to produce food while minimizing hazards to the environment is central to the basic principles of IWM. Consequently, the implementation of IWM involves bringing together weed control strategies whose components have been carefully selected, field-tested in specific agroecological zones, and adapted to the needs of farmers who will use them.

*Model 1. A perennial legume cover crop system:* This model is built around a cover crop (preferably a perennial herbaceous legume) that provides ground cover to discourage weed seedling establishment and mulch to smoother weed seedlings, add organic matter rapidly to soil, reduce soil temperature, promote earthworm activity, fix nitrogen, and release it to the associated crop. The cover crop should be deep-rooted to minimize competition with the crop, and it should not climb on or smother the crop. The perennial cover crop should occupy the field after crop harvest and during the subsequent fallow period. The legume cover crop is often maintained as a living mulch, and crops are planted in rows made by killing strips of the living mulch with a contact herbicide or by a mechanical method. The system is appropriate for most row crops that can be grown in a no-tillage system, and in places where moisture is not a limiting factor. Legumes adapted to a given agroecological region should be selected and field-tested before large-scale on-farm studies are undertaken. Researchable features of this model include the local selection of promising legumes for specific cropping systems, farmers preferences and on-farm testing of specific technologies that are based on this model. Live mulch production systems have been researched (1) and multilocational testing of legumes have been carried out by several researchers.

*Model 2. In-situ mulch-based systems:* This system should be based on annual grasses, legumes or grass/legume mixtures. If the in-situ mulch is an annual, the mulch is naturally produced when the plant cover dies off at the end of rains. The mulch protects the soil during the early rains and smothers weeds, while the decaying mulch adds organic matter and nutrients to the soil during the subsequent cropping season. The effectiveness of weed management technologies that are based on this model depends to some extent on the thickness of the mulch and on its rate of decomposition. Legumes that have shown great promise in this model are mucuna [*Mucuna pruriens* (L.) DC. var *utilis* (Wight) Burck], and tropical kudzu [*Pueraria phaseoloides* (Roxb.) Benth.] (20). One setback in the use of mucuna is that of volunteer seedlings but this can be minimized by slashing the mucuna before its seeds mature.

*Model 3. A system based on legumes with erect stems:* This model is based on using legumes (annual or perennial) for improved fallow management. The cropping pattern in this model is flexible and can be adjusted to meet a wide range of annual and perennial legume plant options. Alley cropping and interplanting with a range of erect annual legumes such as *Crotolaria verrucosa* L. have been shown to reduce weeding frequency in food crops.

*Model 4. A system based on non-leguminous cover crop:* Smallholder farmers in the tropics have for years practiced low-input farming based on mimicking the microenvironment of soils under natural vegetation covers. In the natural bush fallow, plant biomass is produced quickly to restore organic matter, weed pressure is minimized and soil fertility and other soil properties are maintained. In most parts of West Africa, farmers grow "egusi" melon or bitter melon (*Citrullus lanatus* (Thunb.) Matsum & Nakai subsp. *mucospermus* Fursa). This is an excellent example of a technology that has been widely accepted by low-input farmers (9, 19). Other smother crops can be tested for specific low-input production systems in other parts of the world.

## PROSPECTS FOR ADOPTION AND TRANSFER

Research has for many decades focused on increasing yield under high-input conditions as has been practiced for rice in southeast Asia and attempted in many other parts of the developing world. Only recently has some effort directed at developing production technologies under constraints that are faced by low-input farmers. Wherever this approach has been tried, there has been significant low-input farmer adoption of the technologies. An example is the breeding for improved maize and cassava varieties under low soil fertility conditions (10). The adoption and transfer of IWM technologies for improved productivity have to be seen in the context of the socioeconomic circumstances in which farmers carry out their farming activities. Low-input farmers are constantly faced with declining productivity in the face of increasing weed population density. Weeding frequency has unavoidably increased in response to weed pressure. Weed management technologies that merely provide weedfree fields are no longer desirable as a weed management objective rather, these must be linked with sustainable crop yield. Lack of adoption of IWM technologies has in the past been blamed on poor extension services or poor infrastructural development. Mor recently, farmer participatory approaches have been advanced to move the technology adoption process forward. Weed scientists must show a willingness to develop weed management strategies that are based on production conditions in which low-input farming is carried out. This implies a closer linkage with smallholder farmers as partners. It also requires careful assessment of the economics of weed management technologies developed under these conditions.

## CONCLUSIONS

What is urgently needed by low-input farmers is not the introduction of technologies that will necessarily transform low-input production systems but one that will help them to produce their crops on a sustained yield basis. Some weed management strategies that can meet the above conditions have been discussed in this paper. Weed management technologies are location specific. Therefore on-farm testing of models and weed management technologies presented here will need to be carried out in appropriate farmer participatory modes. For the low-input farmers of the tropics, weed management technologies that are cost effective at low-input levels, minimize drudgery, reduce weeding frequency, and contribute to soil fertility maintenance have the best chance of increasing production and keeping low-input farming systems sustainable. Such desirable research initiatives can best work if the necessary funding and backstopping are provided.

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# ENVIRONMENTAL ISSUES AND REGULATORY TRENDS IN WEED MANAGEMENT TOWARDS THE NEXT MILLENNIUM

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*Summary:* Environmental issues, regulatory trends and weed management are not irrevocably linked for all times. They will have to be pulled apart from each other as a result of the changing global politics. Regulation, which has kept an uneasy balance between the scientific community's concept of 'risk' and the public's concern for 'safety', will continue to retain this role, but no longer be the main driving force. Science will re-examine what is meant by good science and technology. The last thirty years have been the years of increasing regulation. In future, the emphasis will swing from what we should not be doing (the legal) to what we should be doing (the ethical).

*Keywords:* weed management, sustainability, ethics, risk perception.

## INTRODUCTION AND HISTORY OF WEED SCIENCE

Zimdahl in his paper *Weed Science: A Plea for Thought* (9), challenges the weed science community to look at the history of their science in order to look towards a future of weed science that is more than just chemical weed control. He writes:

"I want to question the technology that moved us to the level of weed control we can now obtain so easily and rediscover the obvious that has been abandoned as technology has roared on. Forgotten obvious agricultural things, such as crop rotation, may well be worth re-discovering................, technology has diminished such as crop rotation, cultivation, careful land preparation, and multicultural crop environments. These techniques should be examined while simultaneously advancing current, excellent work on chemical control techniques, allelopathy, biological weed control, and integration of methods...........The best technology, whether new or old, will solve a problem and contribute to the solution of other problems rather than solving a problem while creating a series of new problems. There is no scientific or social requirement that every technological innovation, every new herbicide, and every dream of technological achievement must be indulged."

Zimdahl's treatise has as its greatest contribution to the weed management debate his central observation that his own community of scientific experts could well suffer from excessive faith in their own expertise, a moral disease that all experts might have, without them being aware of it. He asks, "Do they neglect all evidence that does not come from within their ranks?" And then goes on to observe, "It is so much more comfortable just to speak to those who understand our language and know the wisdom of our words."

Venturing outside one's own scientific community and learning the language of others, in order to take our true place within the international debates on environmental and humanitarian issues, is something that scientists, especially those within the science based business communities, are slow to consider even as a remote possibility. Only those scientists, who see that the whole scientific enterprise itself is at stake and are aware of what their expertise has to offer within these debates, are motivated to look with fresh eyes at the science that has been their life. They will get away from a stance of automatic self-justification to one that makes bold and truthful assertions about a particular science, because it is not afraid at the same time to admit limited knowledge, fallibility, mistakes or bad judgement. In other words, the future of science depends upon it being regarded as a human endeavour like any other. Collins (3) the innovative sociologist of scientific knowledge asserts:

"We understand the fallibility and interests of financial advisors, lawyers, politicians, art and literary critics, doctors, builders, car mechanics, and travel agents without concluding that they are not more expert in their areas than we ourselves. Neither anarchy nor nihilism follows from the human basis of expertise; instead comes the recognition that there is no magical escape from the pangs of uncertainty that underlie our decisions.

Professional scientists are the experts to whom we must turn when we want to know about the natural world. Science, however, is not a profession that can take from our shoulders the burden of political, legal, moral and technological decision making. It can only offer the best advice that there is to be had. To ask for more than this is to risk widespread disillusion with science with all its devastating consequences."

These two thinkers, whether working within science like Zimdahl, or studying it from the sidelines like Collins, have both commented upon the contradictory expectations placed upon science. Science is expected to be infallible and to be capable of solving all the world's problems. At the same time it is expected to be morally neutral and value free and therefore, logically, to have absolutely no interest in solving the word's problems. Collins concentrates on the dangerous consequences of this paradox actually being believed outside science, and Zimdahl emphasises the marginally worse scenario when the scientist begins to believe it himself. The result is that both far too much and far too little is continually being expected of science, by lay-person and scientist alike.

## PERCEPTION OF 'SAFETY' AND 'RISK'

The science and business of crop protection product research, development, manufacture and sales, faces widespread disillusion, anxiety, and a host of negative images from outside. Some of these are based on facts and sound data, others upon perceptions which, whether true or not, are believed none the less. In the thirty-five years since the publication of Rachel Carson's *Silent Spring* (2) two things have happened to this industry. The first is that it has become amongst the most highly regulated in the world. And secondly, as a direct result of the first, the industry has allowed itself to focus resources and effort almost exclusively upon regulatory matters. Few would argue against the necessary role of the regulator as an all important bridge between society's perception of safety and the scientific community's perception of risk. However, it can also be argued that if there is a tendency, both within and outside the crop protection industry, to view either more or less regulation, or even better or more sophisticated methods of regulation as being the whole answer to the paralysis of the pesticide paradigm, then more is being expected of 'good science' than science, however good, can ever deliver.

Not just the natural sciences but also the social sciences have studied and worked with the concept of 'risk' over the last few years. A landmark was the publication of Beck's *Risikogesellschaft* in 1986 (published in English as *Risk Society* (1). Beck's main thesis is that modern science and technology have created a 'risk society' in which success in the production of wealth has been overtaken by the production of risk. Possibly his most vivid definition of risk is where "one is no longer concerned with attaining something good but rather with preventing the worst" and as a result he questions the whole basis of the science of toxicology as not being about 'safety' at all but rather about "how much poisoning we can get away with." Wildavsky(8) also challenges science but from the opposite perspective, asking, "If claims of harm from technology are false, mostly false or unproven, what does this tell us about science?" He does not agree with Beck about the magnitude of the risk but does agree with him about the significance of culture and society in shaping perspectives on risk. Jointly with Douglas (4) Wildavsky develops this view of risk as a socially constructed phenomenon. Both Beck and Wildavsky criticise strong, controlling and powerful hierarchies, and both accuse these of 'bad science'. But Beck attacks scientific big business for causing the problems and calls for *more* control and regulation to prevent further poisoning and pollution, while Wildavsky pleads *less* regulation because he sees the problem as being the regulators who should have their power withdrawn because they are preventing the wealth creation potential of science from being realised. Both seem to be calling for *good science* to sort out the problems of risk because they see *bad science* as being the problem.

Both Beck and Wildavsky, albeit arguing from very different places to very different conclusions, seem to be calling for a scientific certainty which both their arguments would seem to deny as being possible. Wildavsky [8] looks at many major American environmental disasters such as Love Canal, Agent Orange, Alar, bovine growth hormone, and asbestos, and concludes that in all the cases he cites that the danger was either grossly exaggerated or non-existent. In his opinion science obviously failed on the side of extreme caution, provoking unnecessarily alarmist views about long-term environmental harm. Beck, on the other hand, makes the exact opposite criticism of science because he sees the problem as science throwing caution completely to the wind. He writes:

"There are other 'cognitive toxic floodgates' under the control of risk scientists. They also have really great magic at their command: abracadabra!, shimshalabim! This is celebrated in certain areas as the 'acid rain dance' - in plain language, acceptable level determination or maximum concentration regulation, both expressions for not having a clue. But since that never happens to scientists, they have many words for it, many figures. A central term for 'I don't know either' is 'acceptable level'."

## PROBLEMS OF RISK COMMUNICATION

In view of these extremes of contempt for scientific risk assessment, albeit argued from such diametrically opposed viewpoints, it is not surprising that all those connected with the development, production, selling and use of crop protection products have been forced behind a barrier of regulation from which the only communication deemed possible with those outside is either defensive or reactive. The arguments used against this industry have often seemed so confused and contradictory, that the industry has been inclined to reply with a long list of facts which have absolutely no bearing upon the question being asked. For example, a general question about crop protection product use, its short term harm to the spray operator, his family and community, together with its long term harm to the environment and future generations, really cannot be answered by the stock remarks about coffee containing the known natural carcinogens hydrogen peroxide and methylglyoxal at about 4,000 ppb., while cola drinks contain the known carcinogen formaldehyde at 7,900 ppb. These and similar arguments about a thousand and one different everyday natural and synthetic products, are all aimed at bombarding the questioner with facts which 'prove' that crop protection products are far less harmful. Or, alternatively, there is the long monologue about the benefits of crop protection products and their contribution to feeding the world. The listener will not necessarily dispute these facts but may be forced into a position of appearing to do so, because there is no logical connection between crop protection product safety and the levels of certain natural chemicals in coffee *per se* or the benefits of crop protection products to plentiful food production. This is, however, not to negate the appropriateness to discuss, in a different context, the safety of naturally occurring substances or draw attention to the immense benefits of crop protection products. The inability to answer a question is covered up by blaming the fact/value divide.

Dismissing all problems of communication by describing them as being due to the 'fact/value divide' is so commonplace, that it is rarely examined what exactly is meant by this term, and whether facts given bear any relevance to the questions asked. The industry thinks the problem is that the 'insiders' talk facts, while the 'outsiders' talk values. Hardly ever is it as simple and clear-cut as that. There is no clear distinction between the two because there may be values within facts, and vice versa. Beliefs about the facts shape values and those values, in turn, shape the facts one searches for and how one interprets them when one finds them. It is the job of the regulator to work within this fact/value circle. But the ability to break through it will come from elsewhere. The future of a specific science like weed management will depend on the ability of its practitioners to face the link between the risk culture and real moral issues.

In order to give an example with which to work, it is helpful to focus directly upon one common perception about the crop protection industry as a whole, namely that it is "dumping its nasty old products upon the developing world". The reaction is either to ignore it or, if a specific product or practice is implicated, the respective company firstly reacts with arguments about benefits and economic realities, secondly puts efforts into regulatory support such as more tests and generation of more data, and perhaps more training in particular areas. Regulatory defence is relied upon to provide the answer (i.e. preventing the worst), when the true solution may lie elsewhere, within creative new scientific and business initiatives (i.e. achieving the very best).

## SUSTAINABILITY AND ETHICS

One possible signpost forward from paradigm paralysis to paradigm shift has come from Hart (6) in his paper *Beyond Greening: Strategies for a Sustainable World.* Its publication in the Harvard Business Review alongside an interview with the CEO of Monsanto, Robert B. Shapiro, has made it widely known to those connected with the crop protection business. Hart's main thesis is that while there has been an environmental revolution over the last thirty years, with companies now accepting their responsibilities to do no harm to the environment, the challenge over the next thirty years will be to develop a sustainable global economy. Hart writes:

"Those who think that sustainability is only a matter of pollution control are missing the bigger picture. Even if all the companies in the developed world were to achieve zero emissions by the year 2000, the earth would still be stressed beyond what biologists refer to as its carrying capacity. Increasingly, the scourges of the late twentieth century - depleted farmland, fisheries and forests; choking urban pollution; poverty; infectious disease; and migration - are spilling over geopolitical borders. The simple fact is this: in meeting our own needs, we are destroying the ability of future generations to meet theirs."

Hart goes on to point out that it is easy to see the whole situation in a completely negative light, but states that the positive case is even more powerful. "The more we learn about the challenges of sustainability," he says, "the clearer it is that we are poised at the threshold of a historic moment in which many of the world's industries may be transformed."

According to Hart, the global economy is, in fact, three overlapping economies. The first is the *market economy* which is the commercial world comprising both the developed nations and the emerging economies. The second is the *survival economy*, the traditional village-based way of life to be found in the rural parts of most developing countries; and the third is *nature's economy* which consists of non-renewable resources such as oils, metals and minerals, and also renewable resources such as soils and forests. This last one supports both the market economy and the survival economy. Hart emphasises the interdependence of the three economies which must be brought into balance, whereas at the moment they are three separate worlds in collision with each other.

Accepting the broad outline of Hart's thesis, which he presents in symbolic terms as three interlocking circles, it is important to look at the survival economy and those places where it touches upon and is affected by both the market and nature's economies. What is the area of business strategy that he sees as being fundamental to operating within the survival economy? On the overlap with the market economy he sees the priority as being to build the skills of the poor and the dispossessed. On the overlap with nature's economy, the challenge is to replenish depleted resources. Finally, the central strategy for the survival economy is the fostering of village-based business relationships. Hart draws upon demographic sources to point out that world population is expected to double over the next forty years with 90% of that growth being in the developing nations, with most of it being within the survival economy. If sustainability fails within this economy, then the resulting migration from the depleted land to the already overcrowded and heavily polluted megacities will have catastrophic global consequences. Thus, it is in the best interests of all, that this economy should be nurtured and developed in ways that are suitable for its own particular needs.

For those who are involved with looking at future trends within weed management, there is much food for thought within what Hart has to say. The importance of getting sustainability built into the business strategies makes sense but there are two areas where he both overstates and understates certain areas within his vision of sustainability. Firstly, he overstates the unique and overriding role of large multinational corporations when he says, "Corporations are the only organisations with the resources, the technology, the global reach, and, ultimately, the motivation to achieve sustainability." And secondly he does not underpin this argument with any moral dimension, other than the one that is implied, namely that global sustainability is good. A message that paints large corporations as saviours of the world requires a better constructed moral argument that amounts to something more convincing than: we are the ones that can do it because we are big and powerful and want to stay that way.

Is sustainability ethical? It could be argued that the slave agriculture of ancient Mesopotamia was sustainable, certainly more sustainable than many of the small family owned plots in much of the modern day survival economy. But does that therefore mean that slavery becomes ethically acceptable, if it is the only way to achieve global sustainability? Thompson (7) by examining the competing agricultural ethical philosophies of productionism, stewardship, economics and holism, argues for an open-ended understanding of sustainability. Sustainability is not an ethic in itself, it is rather a general goal for reform, but change will come by a combination of the ethics of stewardship, economics and holism. In other words, there will always be a tension between agricultural ethics and environmental ethics, with environmentalists using chemical poisoning as the target of their attacks when what they are really attacking is agriculture itself, but, as Thompson concludes, "The tensions created when partial philosophies and unachievable ideals are combined only reveal the irony and incompleteness of any attempt at intelligent action. They do not excuse our indolence".

## WEED MANAGEMENT IN THE NEXT MILLENNIUM

Where is weed management going in the next millennium? The last thirty years have seen the growth of regulation which has kept in an uneasy balance the concepts of risk assessment within the scientific community and the concept of safety within the politics of environmental concern. The next thirty years will see enormous changes, but less in the areas of regulation which will continue to adapt to new technology within the continuing call for ever safer and safer options. (Concerning crop protection product manufacture, however, regulations and their rigorous enforcement have for some time still to play a major role, if desired standards of operation are to be achieved globally.) The real changes will happen outside regulation or codes of conduct whether international, governmental or industry generated, which will increasingly be seen as only preventing the worst and nothing whatever to do with creating the best. The changes will come by way of a new politics, less driven by pressure from one particular ideology or another, but developing from what can be described as 'a politics of life decisions'.

The political changes which are experienced at the moment make very little sense if judged in terms of 'right' or 'left' or by ideologies based on loyalty to a tradition, class or particular theory. Political decisions will increasingly flow from freedom of choice, and the creation of morally justifiable forms of life which promote self-actualisation in the context of global interdependence. This will be based upon ethics which are concerned with answering the one question, "How should we live?" as analysed by Giddens (5) in *"Modernity and Self-Identity"*. Thus the area of science, or the business, or the political party, or the Non-Governmental Organisation, or the university department that through its actions is best answering this question will be the one that prospers. And it will be those who manage through partnerships involving two or three of any of these which will be most likely to prosper most. Because the basis of 'life politics' is the choice of life over death within the awareness that unless we live and work together we will die together.

Weed management will, in terms of science contain that mixture of the very new including many advances in chemicals and many new biological techniques. But where the answer to "How should we live?" is a mixture of many techniques including crop rotation, education in cultivation techniques and many older technologies, including the older chemicals where appropriate, there will be no more accusations of first world companies dumping nasty old chemicals in the third world once there is a real choice being made. Those companies that work with others to make that choice a real one, coming from the user and from within his community, will continue to contribute to the development of that country.

Zimdahl (9) chose to take a look at his own community and expected some anger and resentment as a result, not because he was questioning its science but its values. Yet as a result of his treatise, there were many more weed science students set free to look at creative new uses of old technology which could well be more appropriate in certain circumstances. It is to be hoped, that when those within the community that manufactures and sells new technology, are enabled to recognise the ethical dilemmas that arise from operating within such a well regulated industry, with its resulting legalistic culture, they will be set free to focus their creative science upon the user in the developing world as a real human being living within a particular environment, with particular needs, problems and priorities, rather than simply as a number within a risk assessment calculation. That way they will be able to focus on his weed problem and the best way to manage it, a holistic view of appropriate technology for the small farmer, within which safe-use of a herbicide is only one important element among many.

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# PHENOTYPIC PLASTICITY AMONG WEEDS OF DIRECT-SEEDED RICE IN CALIFORNIA

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*Summary*: Phenotypic plasticity has long been suspected to be common in weeds, yet has rarely been verified. We searched for firm evidence of plasticity among important weeds of California direct-seeded rice. The six weeds for which reports or data were available all showed some form of phenotypic plasticity, suggesting that it is a common trait. The most common plant responses were in dry matter allocation and plant height. Widespread plasticity among important weeds has many consequences for short- and long-term control. It also suggests that dynamic integrated weed management programs will be required to reduce weed competition in direct-seeded rice.

*Keywords*: weed ecology, morphology, water-seeded rice, direct-seeded rice

## INTRODUCTION

Weed control in direct-seeded rice is critical because weeds germinate simultaneously with, or ahead of, the rice crop. California growers have come to depend on the repeated use of selective herbicides for weed control, but factors such as herbicide resistance and concerns about environmental pollution suggest that herbicide use is likely to decline (9). Thus, weed control is expected to become more difficult, and knowledge about weed biology increasingly more critical to maintaining high yields in Californias water-seeded system. Similar concerns exist in many crops, and weed control research has increasingly focused on integrated weed management strategies (7, 12, 19). However, the design and use of integrated weed management programs have been limited by the lack of basic knowledge about weed biology (9, 13, 17).

Phenotypic plasticity is the ability of a plant to change its morphology, physiology, or both, in response to environmental conditions (16). It is thought to be a widespread and important factor for the success of weeds in agroecosystems (2, 10), and has been described as an ideal ecological weed trait (1). Despite this, plasticity in agronomic weeds has rarely been studied (13).

After experiments showed that redstem (*Ammannia auriculata* Willd. and *A. coccinnea* Rottb.) responded plastically to rice competition (6), we tried to determine the general prevalence of phenotypic plasticity among important rice weeds. We found pertinent information for six weeds, and discuss some implications of widespread phenotypic plasticity for weed management in direct-seeded rice.

## MATERIALS AND METHODS

We selected a search list of important weeds from the most widely distributed (3), economically important (9), emergent weeds in California rice. Our search focused on those weeds most likely to affect rice production in California. Searches by genus and species names were usually feasible, because few of these weeds have been extensively studied. In other cases, e.g. *Echinochloa* spp., the number of published reports required searching for particular keywords, such as plasticity, variation, or morphology. For this survey, we only considered information about relevant weed species, not information about related species within genera.

In one case, we analyzed data from a 1992 target plant pot experiment with smallflower umbrella sedge (*Cyperus difformis* L.), that had not been evaluated previously for phenotypic plasticity (5). Full experimental details are given by Breen (1995), but briefly, single plants were grown alone, or in competition with four rice plants. Several response variables were measured at four paired harvests over the season. The data for each harvest was analyzed by balanced or unbalanced ANOVA, as appropriate, on height, dry matter, shoot:root dry matter ratio, and specific stem length (SSL; cm/g) Bartlett's test was used to identify data with unequal variances, and these were $\log_e$-transformed for ANOVA (14).

## RESULTS AND DISCUSSION

*Smallflower umbrella sedge data*: Despite great differences in smallflower umbrella sedge shoot dry matter between treatments (P=0.001; Fig. 1A), no differences in plant height were detected (P=0.2; Fig. 1B) until the final harvest, when plants grown in competition were taller (P=0.01). At 38 and 49 days after seeding, total and root dry matter of smallflower umbrella sedges grown in competition were much smaller than those of plants grown alone (P=0.005). No difference in shoot:root drymatter of plants grown in competition and plants grown alone was detected at 38 days after seeding (P=0.9), but plants grown in competition had greater shoot:root ratios at 49 days after seeding (P=0.01). Finally, SSLs of plants grown in competition were much greater than for plants grown alone at all four harvests (P=0.001).

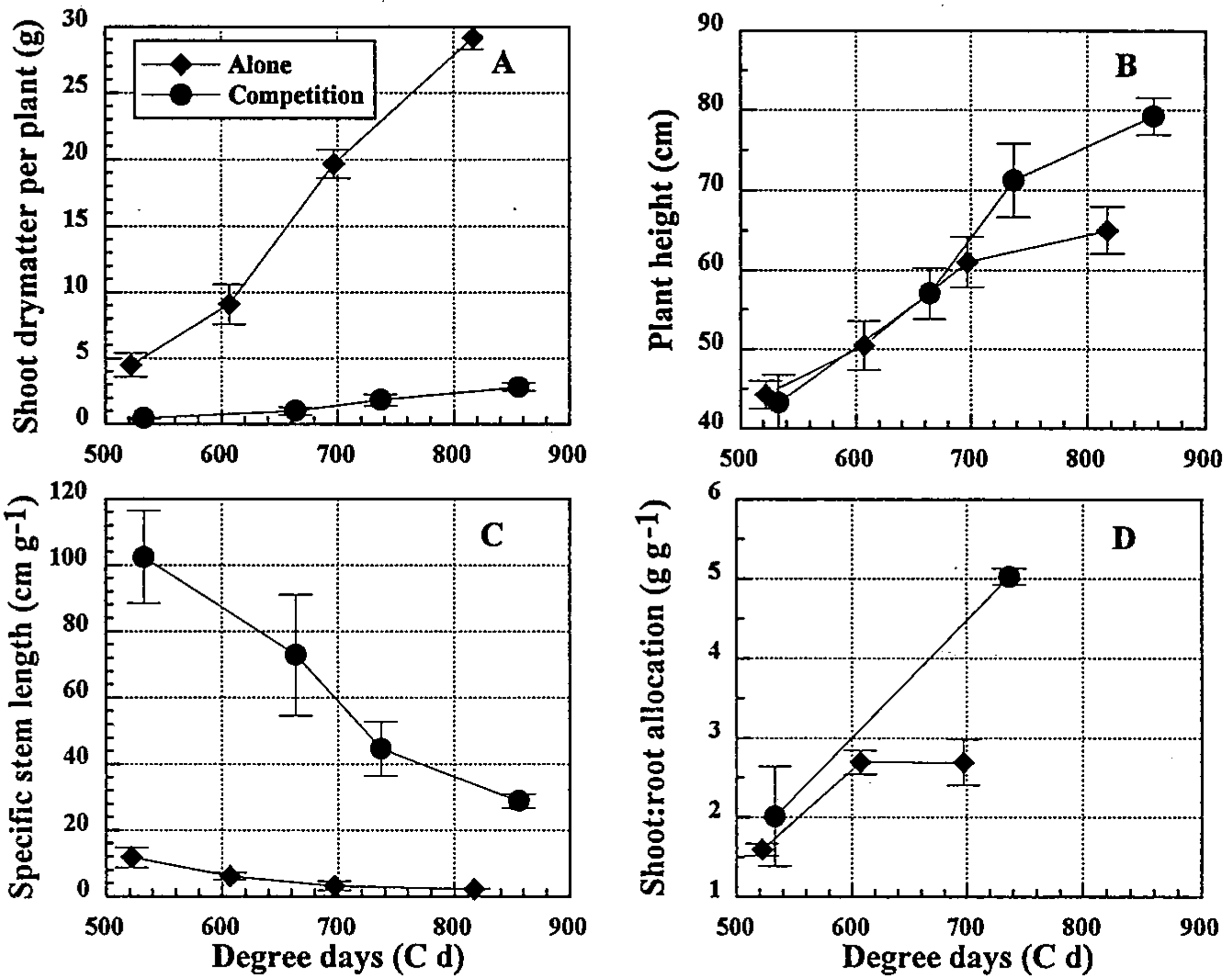


Figure 1. Smallflower umbrella sedge growth (s.e.) alone and in competition with rice: A) shoot drymatter per plant, B)plant height, C) specific stem length, D) shoot:root drymatter allocation.

Despite a 90% reduction in drymatter, smallflower umbrella sedges grown in competition equaled and eventually exceeded the height of plants grown alone. This response seemed partly due to increases in both shoot:root dry matter ratios and SSLs (i.e., thinner, more elongated stems). These responses were similar to those observed for redstem (6). Both weeds seemed to employ a ⊛shade avoidance plant strategy in rice competition, in which stem elongation was favored over leaf area and root development so that the top of the plant (youngest leaves) was kept sunlit (18).

*Phenotypic plasticity survey:* Besides the smallflower umbrella sedge data analyzed above, we found reports for five weeds (Table 1): redstem (6); barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), and early and late watergrasses (*E. oryzoides* (Ard.) Fritsch. and *E. phyllopogon* (Stapf) Koss, respectively) (4); California arrowhead (*Sagittaria montevidensis* ssp. *calycina* Cham. and Schlecht.) (11); and common cattail (*Typha latifolia* L.) in two separate studies (8, 20). Notably, all six weeds showed phenotypic plasticity.

Table 1. Type(s) of phenotypic plasticity shown by California rice weeds and references, in order of distribution[1].

| Weed Species | Common name | Plastic response(s) | Reference(s) |
|---|---|---|---|
| *Sagittaria montevidensis* | California arrowhead | Foliar development | Kaul, 1991 |
| *Ammannia coccinea, A. auriculata* | Redstem or redberry | Allocation, height | Caton, Foin, and Hill, 1997 |
| *Echinochloa oryzoides, E. phyllopogon* | Early/late watergrass | Allocation, life history | Barrett and Wilson, 1981 |
| *Typha latifolia* | Common cattail | Allocation, height | Grace and Wetzel, 1981; White and Sinclair, 1979 |
| *Cyperus difformis* | Smallflower umbrella sedge | Allocation, height | Breen, 1995 |
| *E. crus-galli* | Barnyardgrass | Allocation, life history | Barrett and Wilson, 1981 |

[1]Barrett & Seaman, 1980

Plasticity in dry matter allocation was shown by five of the six weeds; this response was not measured for California arrowhead. Redstem and smallflower umbrella sedge responded to competition by allocating more biomass to shoots, while *Echinochloa* spp. responded to later emergence by increasing allocation to shoot and reproductive growth. Common cattail allocated more biomass to roots under nutrient-limited conditions, but produced the highest leaf volume:leaf biomass ratios under light-limited conditions.

Plasticity in plant height was also common, shown by three weeds; it was not reported (perhaps it was not measured) for *Echinochloa* spp. or California arrowhead.

The results for these six weeds strongly suggest that phenotypic plasticity is common among California rice weeds. The survey found information supporting the presence of plasticity in most of the problematic rice weeds in California, except ricefield bulrush (*Scirpus mucronatus* L.) and bearded sprangletop (*Leptochloa fasicularis* (Lam.) Gray). Regardless, we concluded that most of the weeds which management efforts focus on in California rice are phenotypically plastic. This has many consequences for short- and long-term weed management, but we discuss only the most important for each in this paper.

The most critical facet of weed phenotypic plasticity, over the long-term, is that it maximizes reproductive output. When these weeds escape control, plasticity maximizes the number of seeds produced, or with perennials the production of vegetative structures such as rhizomes, corms or tubers. Of course, plasticity does not enable the weeds always to meet their potential, because crop interference alone limits weed growth dramatically (above, and 6). Nevertheless, it does allow the weeds to survive and reproduce when they might not otherwise, by altering their growth in response to the conditions experienced. In such situations, competitive effects may be substantially reduced, but the weed strategy is a success because of reproduction.

Although the primary concern is for weeds growing within the crop, plasticity may also be important for weeds growing unchecked in field margins or other suitable habitats. Two reasons for this are the potential for seed dispersal in water, and the very many seeds that some species produce. For example, small-seeded smallflower umbrella sedges produce hundreds of thousands of seeds per plant in optimal conditions (15). Phenotypic plasticity helps to ensure the weeds continued presence in the field, and thus the necessity for control year after year (assuming the weed in question is competitive).

The implication that plasticity enables these weeds to respond to common crop management and control actions, contributing to their escape, is important for short-term management. For example, the responses of redstem (6) and cattails (8, 20) to plant density or spacing could reduce the effectiveness of manipulating these variables for cultural control. Likewise, because California arrowhead weeds respond plastically to water depth (11), this strategy is a less effective control practice. We also have evidence that redstem and watergrass plasticity enabled them to penetrate the rice canopy even after germinating as much as two weeks after rice planting (Gibson and Caton, unpublished data). This ability may reduce the effectiveness of early chemical control.

However, plasticity does not confer upon weeds perfect protection from control. To the extent that management practices can be integrated and optimized, weed responses will be less effective. For example, equally effective herbicide applications made later, combined with more competitive cultivars or optimized spacing and density, might limit the abilities of watergrass and redstem to penetrate canopies from late regrowth. Integrating weed management in direct-seeded rice probably means maximizing crop interference, water suppression, and chemical control efficacy, and optimizing them with each other as far as possible.

Facing widespread phenotypic plasticity, single control practices may reduce weed growth, but over the long-term are probably incapable of preventing infestations and so, ultimately, yield losses. Thus it becomes apparent why integrated management strategies seem necessary for weed control in direct-seeded rice (9), and perhaps in other cropping systems (7, 12, 19). Furthermore, a single integrated management program seems unlikely to control yield losses and weed infestations when repeated indefinitely, because plasticity and genetic diversity may enable rice weeds to adapt to the suite of cultural and chemical control actions used. Instead, even integrated management strategies will probably have to be varied. Hence it is important to have several effective herbicide options, and a range of weed suppressive cultural practices (e.g. combinations of water depths, competitive cultivars, densities and planting dates).

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# THE BIOLOGY AND CONTROL OF PARTHENIUM WEED (*PARTHENIUM HYSTEROPHORUS* L.)

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*Summary*: Parthenium weed (*Parthenium hysterophorus* L.) is an annual herbaceous plant native to the tropical Americas, which now occurs in south and east Africa, southern Asia and Australia. In Australia it has become widespread in grazing land in central Queensland and has spread to northern New South Wales. It causes direct losses to the grazing industry and is a human health hazard, causing allergic rhinitis and contact dermatitis. The Centre for Tropical Pest Management (CTPM) seeks to develop and implement cost-effective, environmentally friendly methods of control for parthenium weed. This is achieved through collaborative research and technology exchange and concerns the topics of biology, ecology and biocontrol. The studies on biology and ecology involve the characterization of ecotypes using genetic finger printing techniques, investigating the role of allelopathy, seed banks and phenological attributes in the weeds persistence mechanism(s). Process-based simulation models are being used to monitor and predict future spread. Biological control is developed and enhanced through the use of plant-feeding insects and pathogens. Studies on the efficacy of one biological control agent, *Epiblema strenuana*, a stem galling moth, has shown there is a critical age period when the agent must infest the weed. If infestation occurs at a later stage in the life of parthenium weed then control is poor. In addition the presence of competition from native pastures will enhance the efficacy of the biological control agent. The present program undertaken at CTPM builds on earlier work carried out by the University of Queensland (UQ), the Queensland Department of Natural Resources (QDNR) and the CSIRO.

*Keywords:* seed biology, biocontrol efficacy, weed biology, weed spread

## INTRODUCTION

*Weed biology*: Parthenium weed (*Parthenium hysterophorus* L.) is a herbaceous ephemeral, member of the Asteraceae (6), reaching a height of 2 m in good soil and flowering within 6 to 8 weeks of germination. Large plants can produce up to 15,000 seeds which can be distributed by floating on still or flood waters, or in mud adhering to animals, vehicles and machinery (2). It is thought that most seed germinate within 2 years if conditions are suitable, although a portion of buried seed may remain viable for several years. Parthenium weed does best on alkaline to neutral clay soils, but will grow less prolifically on a wide range of other soil types. The plant's water requirements are relatively high, and both germination rate and growth are limited by poor rainfall (7).

*Distribution*: Parthenium weed now occurs throughout the tropical and subtropical Americas from southern United States of America (USA) to southern Brazil and northern Argentina. Parthenium weed was accidentally introduced into India in about 1956 and has since spread over most of the country. It is now in southern China, Taiwan and Vietnam but not reported from other south-east Asian countries. It is present in several Pacific island and African countries. Parthenium weed has been introduced into Australia from North America on at least two separate occasions. The most serious introduction occurred in 1958, where seed was brought in as a contaminant of pasture grass seed from Texas, USA. This infestation originated in the Clermont area and did not spread very quickly until the mid 1970s. However, rapid spread since this time has led to 170,000 $km^2$ or 10% of Queensland being infested (3). The other introduction occurred near Toogoolawah in south-east Queensland. It has been suggested that this occurred during the 1940s and was due to the movement of aircraft and machinery parts from the USA. This infestation has not spread nearly as extensively as the one at Clermont. There are now minor infestations in New South Wales and the Northern Territory.

*The parthenium weed problem*: Parthenium weed and related genera contain sesquiterpene lactones which induce severe dermatitis and other allergic symptoms. Agricultural losses can also be severe. In India, parthenium weed causes yield losses of up to 40% in several crops and is reported to reduce forage production by up to 90%. In Australia parthenium weed is a serious problem in perennial grasslands in central Queensland where it can reduce beef production by as much as A $16.5 million annually (3). Stock, especially horses, suffer allergic skin reactions when grazing infested paddocks. Parthenium weed is generally unpalatable, but cattle and sheep will eat it when feed is scarce. Consumption of large amounts will produce taints in mutton and milk or kill stock.

*Control*: In most areas of the world the high cost of herbicides prohibits their use in perennial grasslands. Control can be achieved by maintaining good grass growth to maximise competition against the weed; this is achieved by lowering stocking rates. When individual parthenium weeds are found, or the weed is a problem in certain crops, control can be achieved by using 2,4-D or residual herbicides such as atrazine. Biological control is feasible and the search for natural control agents is on-going in Australia and India.

## CTPM APPROACH

The objectives of the program at the CTPM are three-fold. Firstly, to improve our understanding of the biology and ecology of the weed. This includes studies on seed biology, competitive ability, awareness of distinct biotypes, the future spread of the weed and its allelopathic potential. Secondly, the development of improved methods of biological control using insects and pathogens. This includes studies designed to improve the effectiveness of various agents. Thirdly, the development of ways to inform extension workers and farmers about new biological control methods, and how to integrate these into their weed management plan (Fig. 1).

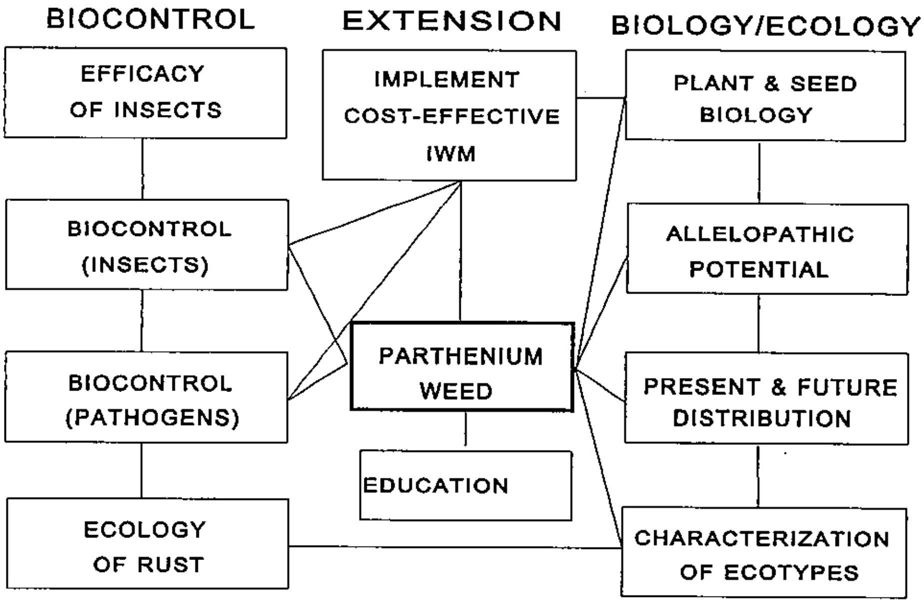


Figure 1. The interrelationship of the sub-projects in the overall CTPM team effort to control parthenium weed.

## BIOLOGY AND ECOLOGY SUB-PROJECT

The objective of this sub-project is to undertake a comprehensive study of parthenium weed that will identify the life stages best targeted for biological control and other management methods. In addition, the sub-project will provide data for predicting the potential spread of the weed under present and future climate conditions, and for determining the best intergrated weed management (IWM) option.

*Seed Biology*: We are measuring seed production and testing for viability, dormancy, and ability to germinate at a wide range of temperatures and substrate moisture levels. Other studies are investigating seed banks from several central Queensland locations. So far we have confirmed that the weed produces vasts amounts of seed (>15,000 per plant) and is a major part of the soil seed bank in central Queensland. At two sites studied, parthenium weed accounted for between half and two thirds of the total seed present. Long term burial studies have shown that after 24 months 90% of the seed recovered is still viable. This indicates that buried parthenium weed seed remains viable for much longer than previously thought. This has implications for future management of the weed, particularly in cultivated areas where seed burial occurs regularly.

*Phenology*: Plants are being grown under controlled environmental conditions using different temperature and photoperiod regimes. We are gathering data on phenology, dry matter production and allocation and reproductive output. The results so far have demonstrated that when plants are grown under conditions simulating those of a cool, damp summer (23/13°C d/n, 14.5 h photoperiod) similar to that of Victoria, Australia, plants are able to survive and, even though under these extreme conditions, produce large amounts of seed. This indicates that parthenium weed has the potential to spread in Australia to as far south as latitude 43°S and still retain a high reproductive ability.

*Biotypes*: Most weeds, including parthenium weed, have a wide genetic base in their native range but possess only limited genetic variation following introduction in to a new country. The purpose of this study is to determine how many distinct biotypes of this weed are present in Australia, how they relate to each other and how they relate to those from overseas. The results so far indicate that there are two distinct biotypes present in Australia and that both are not closely related to those found in India but do have some similarity to those present in North America.

*Allelopathic potential*: The successful spread of parthenium weed in India may be partly attributed to its allelopathic properties (5). In the natural situation the main method of allelopathy is through the release of phytoinhibitors from the mature plant to the soil through leaching from the leaves and/or shoots, the roots and during decomposition of the residues in the soil. Several sesquiterpene lactones and phenolics are thought to be the water soluble compounds involved in these allelopathic responses. A study was undertaken to provide information on the allelopathic potential of the central Queensland parthenium weed plants (1). Leaf aqueous leachates significantly inhibited the germination of climbing buckwheat, liverseed grass, buffel grass and parthenium weed but not sunflower. In addition seedling growth (measured by biomass production) of sunflower, liverseed grass, climbing buckwheat and buffel grass were all significantly depressed by leaf leachates, while a slight stimulatory effect was observed on parthenium weed. The most sensitive species to the leachate applied at the seedling stage was buffel grass, which exhibited significant reductions in shoot and root biomass as well as plant height.

*Potential spread*: Data sets are being developed that will help predict the potential spread of parthenium weed under present and future climatic conditons. From this it may be possible to determine the best practice management options for various areas. It seems that the climate change predicted for Australia will advantage parthenium weed and not the native grasses in the rangelands where it is found. Parthenium weed should also benefit from the projected increases in the frequency of extreme events such as flooding, which will facilitate spread of its seed. We have modelled the probability of invasion and occupation of Australia under different climatic and management regimes. The data obtained is being integrated into descriptions of risk that will be used by land managers in the development of property management plans. The model used is CLIMEX, a computer program designed to predict the distribution of plants, based on climatic preferences. Glasshouse data taken to validate this model so far shows that parthenium weed will increase in dry weight by as much as 86% under elevated $CO_2$ conditions. The plants will also be 60% taller with 105% more flowers (Table 1).

Table 1. Performance of parthenium weed growing under ambient (360 ppm) or elevated $CO_2$ concentrations (480 ppm)

| Factor | Ambient $CO_2$ | Enhanced $CO_2$ |
|---|---|---|
| Flowers per plant | 468.3 | 958.2 |
| Plant height (cm) | 72.1 | 118.4 |
| Dry weight (g) | 6.3 | 11.7 |

## BIOLOGICAL CONTROL SUB-PROJECT

A biological control program involving the introduction of insects from the Americas started in Australia in 1975 and is still in progress. By 1995, seven species of insects had been released but only one, the moth *Epiblema strenuana*, was exerting significant control on the weed. A rust fungus *Puccinia abrupta* var. *parthenenicicola* has been recently released but drought conditions have hampered its establishment.

All insects are now established in at least some areas of Queensland. Virtually no evaluation of their effect on the plant has been undertaken. Under a new CTPM initiative which started in 1995, evaluation studies are now underway to investigate the impact of the stem galling moth *E. strenuana* on parthenium weed under glasshouse conditions. The results suggest that moderate numbers of *E. strenuana* larvae can significantly reduce the height, flower and seed production (Figure 2) if the biocontrol agent can get onto the host weed in the first 30 days after emergence. Competition from buffel grass intensifies the effects of *E. strenuana*. Another major evaluation of the impact of biocontrol agents has started with field and laboratory experiments funded by the QDNR.

A major project funded by the Meat Research Corporation is investigating the summer-active fungal pathogens attacking parthenium weed in Mexico. Based at the CSIRO field station in Vera Cruz, field studies over two full seasons are determining the natural host-range and phenology of the pathogens. These are supplemented by laboratory studies in the UK to test selected pathogens against a range of related plants, native to Australia or of economic importance. If the test results are satisfactory, one or more pathogens will be imported and released in Queensland.

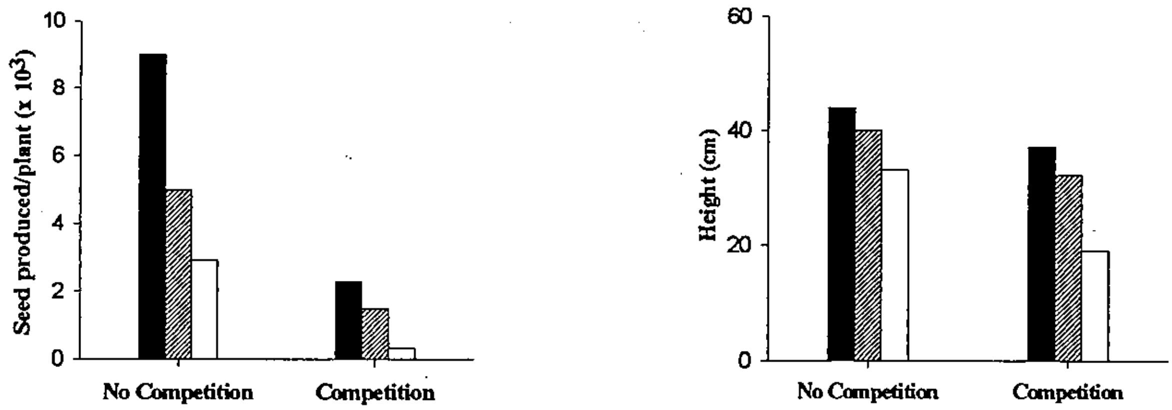


Figure 2. Parthenium weed seed production and height attained in the absence of the biological control agent (black bar), and the effect of *Epiblema strenuana* when applied to young plants (approximately 30 days old - shaded bar) or old plants (approximately 55 days old - white bar) in the presence or absence of competition from buffel grass.

## EXTENSION AND EDUCATION SUB-PROJECT

We believe that long-term parthenium weed management requires a flexible approach which is well integrated into farming systems in both a technical and sociological sense. We are adopting a participative process which will ensure that new strategies developed fit into the existing farming practices and therefore have a good chance of successful adoption. Recently a workshop on parthenium weed was held at Rockhampton (October 1993). Participants included landholders, Government policy makers, extension officers, scientists and research funding bodies. Out of this workshop came a priority action plan which has provided a focus for research extension and education. We now have involvement with the central Queensland community and farmer groups through our own Parthenium weed Study Group (PSG) and through the central Queensland Landcare Parthenium Action Group (PAG). These groups allow stakeholders to retain a feeling of ownership of problems, opportunities and solutions. Posters, brochures, news releases, TV and radio interviews, field days and options for community education have been developed through the PSG and PAG.

## CONCLUSION

By bringing together scientists from UQ, DNR and CSIRO, together with Landcare groups and interested graziers, the CTPM is able to investigate many aspects of the ecology and control of this important weed. Out of this joint effort will come improved management methods which can be applied throughout its present and potential range.

## ACKNOWLEDGEMENTS

The authors are grateful for financial support for the biological and ecological studies from GRDC and for the biological control program from MRC, CTPM and DNR.

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# INFESTATION OF *PENNISETUM SETOSUM* (SWARTZ) L. C. RICH IN SOUTHERN THAILAND AND EVALUATION OF LEGUME COVER CROPS FOR ITS CONTROL

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*Summary*-. The levels of infestation of *Pennisetum setosum* along roadsides varied indicating some relationship to land use; the heavily infested roadsides were located by waste areas and tree plantations, while the sparsely infested roadsides were bordered by rice and upland crop fields. Survey of the *P. setosum* stands in several *Pennisetum*-infested plantations showed highest infestation of *P. setosum* with 276/m$^2$ in shoot number and 5 kg/m$^2$ in dry weight. Growth of four legume cover crops for 12 weeks showed that *Mucuna pruriens* established highest LAI, followed by *Lablab purpureus, Canavalia ensifomis* and *Calopogonium catruleum.* Growth of *P. setosum* for 12 weeks in mixed planting with cover crops was suppressed primarily by *M pruriens,* followed by *C. ensiformis* and *L. purpureus.*

*Keywords*: *Pennisetum setosum*, legume cover crops

## INTRODUCTION

*Pennisetum setosum* (Swartz) L. C. Rich is an introduced perennial weed, aggressively extending its distribution in Southern and Eastern Thailand (4). It is most commonly found as a weed in plantation crops and roadsides causing troubles in those areas (2). In the plantations legume cover crops are sometimes used for soil improvement (7) and have been reported to have the ability of legume cover crops to suppress weeds (1, 6). Therefore, in order to investigate the possibility of *P. setosum* control using cover crops, this study was conducted to determine the distribution and stand structures of *P. setosum* in Southern Thailand, as well as to evaluate weed suppression characteristics of four legume cover crops.

## MATERIALS AND METHODS

*Survey of infestation of P. setosum*: This survey was conducted during the rainy season from August to December in 1996. In four provinces in SouthernThailand (Songkhla, Phattalung, Trang and Krabi), nine locations heavily infested by *P. setosum* were selected, and through Trang and Krabi provinces seven locations were selected. Coverage of *P. setosum* was estimated for 2x5 m$^2$ quadrats and plant height, density and biomass were measured for smaller quadrats therein 0.5 x 0.5 m$^2$: Songkhla and Phattalung; 1x1 m$^2$: Trang and Krabi. The survey was conducted at three points per location, 30 m apart from each other. Plantation crops were young rubber trees, most of which were less than 10 years old, and in one location in Songkhla cashew nuts. Level of *P. setosum* infestation along roadsides was visually measured at every 500 m according to the sociability grades of Braun-Blanquet method (5), along approximately 710 km of highway and regional roads in Songkhla, Phattalung, Trang and Krabi province, from a moving car. The use of lands adjacent to roadsides was recorded at the same time.

*Evaluation of legume cover crops*: Experiments were carried out from 20 December 1996 to 10 March 1997 in a greenhouse at Botany and Weed Science Division, Department of Agriculture, Bangkok, Thailand. *Canavalia ensiformis* DC., *Calopogonium caerulcum* (Benth.) Sauv., *Lablab purpureus* (L.) Sweet and *Mucuna pruriens* (L.) DC. var. *utilis* (Wight) Burck were used in this experiment. Cover crops were sown at the rate of four plants/pot in three cement containers, 76x66x32 cm filled with 10 L soil. Coverage of each cover crop was estimated visually every week until 8 weeks after sowing (WAS). At 12 WAS, plants were harvested by stratified clip technique. In a second experiment, growth of *P. setosum* in mixed planting with legume cover crops was studied. Each cover crop and *P setosum* were sown in similar cement containers as the previous experiment. Planting rates of cover crops and *P. setosum* were four and nine plants/pot, respectively, and nine plants/pot of *P. setosum* as a control. Shoot number per plant and dry weight of *P. setosum* per pot were measured at every 2 WAS and at 12 WAS, respectively.

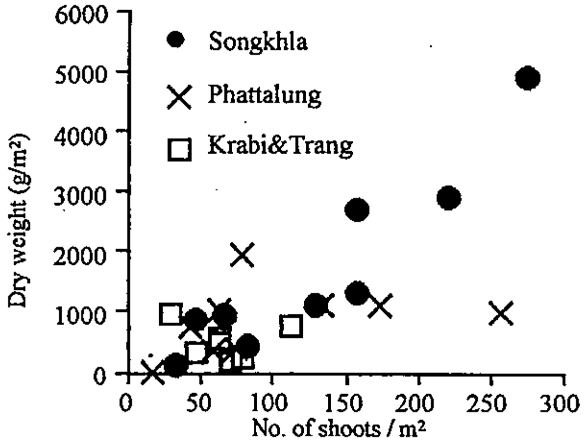


Fig. 1. Structures of *P. setosum* stands in the surveyed areas.

Table 1. Infestation differences of *P. setosum* with reference to roadsides and areas of varying land use.

| Adjacent area | Number of surveyed units [1] Sociability grades [2] (SG) 0 | 1 | 2 | 3 | 4 | 5 | M.S.G.[3] |
|---|---|---|---|---|---|---|---|
| Rubber | 550 | 82 | 70 | 50 | 27 | 14 | 0.7 |
| Young Rubber | 7 | 2 | 1 | 2 | 0 | 1 | 1.2 |
| Oil palm | 11 | 9 | 13 | 9 | 8 | 1 | 1.9 |
| Coconut palm | 37 | 4 | 8 | 0 | 2 | 0 | 0.5 |
| Orchard | 49 | 9 | 7 | 7 | 4 | 2 | 0.9 |
| Paddy field | 328 | 13 | 7 | 2 | 1 | 0 | 0.1 |
| Upland crop field | 23 | 2 | 1 | 1 | 0 | 0 | 0.3 |
| Urban | 793 | 65 | 31 | 18 | 9 | 0 | 0.2 |
| Waste area | 277 | 58 | 48 | 27 | 28 | 8 | 0.9 |
| Bare land | 48 | 5 | 3 | 5 | 0 | 0 | 0.4 |
| Marsh & swamp | 25 | 5 | 1 | 0 | 0 | 0 | 0.2 |
| Others | 18 | 0 | 2 | 0 | 0 | 0 | 0.2 |

1) Surveyed unit : 500m.
2) Sociability grades of Braun-Branquet; 0, not found; 1, a few scattered plants; 2, a few small groups of plants; 3, dotted small groups; 4, dotted large groups; 5,equally grown like a carpet.
3) Mean Sociability Grade = Summed grades/Total number of surveyed units.

Table 2. Dry weight of *P. setosum* in mixed planting with cover crops.

| Cover crop | Mean (g / pot) | S.D. | % of Control |
|---|---|---|---|
| No cover crop | 119.6 | 10.4 | 100.0 |
| *C. caeruleum* | 79.8 | 20.3 | 66.8 |
| *C. ensiformis* | 9.8 | 2.0 | 8.2 |
| *L. purpureus* | 15.6 | 13.9 | 13.1 |
| *M. pruriens* | 1.9 | 1.9 | 1.6 |

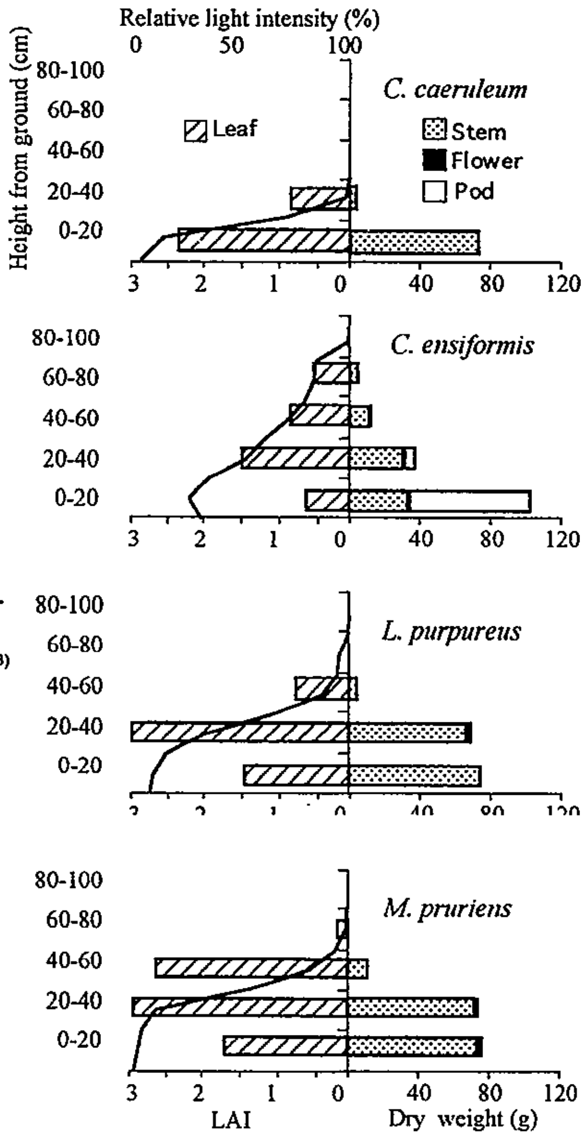


Fig.2. The canopy structure of each cover crop.

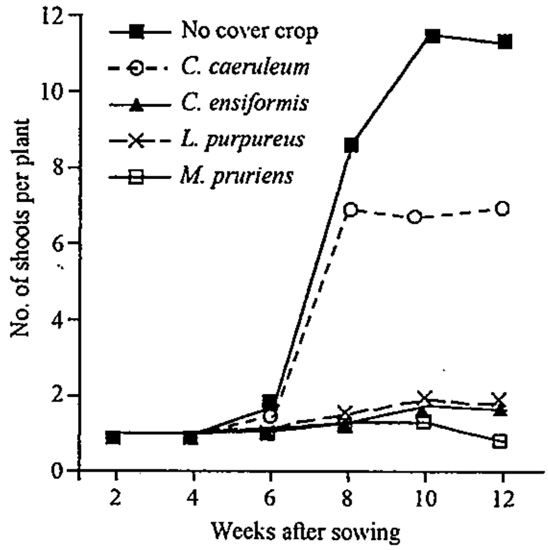


Fig.3 Changes in shoot number of *P. setosum* in mixed planting with cover crops

## RESULTS AND DISCUSSION

*Survey of the infestation of P. setosum*: The structure of *P. setosum* stands varied largely depending on the location (Fig. 1). Maximum amount of *P. setosum* in the almost pure stands was 276/m$^2$ in shoot number and 5 kg/m$^2$ in dry weight. Plant height of *P. setosum* varied from 36-380 cm among the quadrats, but mostly between 200-300 cm. Panicles/quadrat also differed greatly, with only a few where the plant height was less than 200 cm. Levels of infestation at roadsides varied according to land use next to roadsides; most of the heavily infested roadsides were located adjacent to waste areas and tree plantations, while lower levels of infestation were found on roadsides along cultivated fields of rice and upland crops (Table 1).

*Evaluation of legume cover crops*: In pure stands *M pruriens* covered more than 80% of ground at 2 WAS, followed by *C. ensiformis, L. purpureus* and *C. caeruleum* at 3, 4 and 6 WAS, respectively. Leaf area index (LAI) of *M pruriens, L. purpureus, C. ensiformis and C. caeruleum* was 10.0, 5.9, 3.5 and 3.2, respectively. Leaf distribution varied greatly between species, tallest canopy in *C. ensiformis* and shortest canopy in *C. caeruleum* (Fig. 2). Relative light intensity (RLI) under the canopies of *M. pruriens, C. caeruleum, L. purpureus and C. ensiformis* (at the ground level) at 12 WAS was 3.8, 6.4, 10.6 and 33.7, respectively. The value of LAI and RLI between cover crops generally showed opposite tendency except *C. caeruleum* which had low values of LAI and RLI. In the case of *C. caeruleum,* short canopy was attributed to low value of RLI (Fig. 2). In the second study on the growth of *P. setosum* in mixed planting with legume cover crops, the shoot number of *P. setosum* increased remarkably between 6 and 10 WAS in control plot, but scarcely increased in *C. ensiformis, M pruriens and L. purpureus* plots throughout the 12 weeks (Fig. 3). Dry weight per pot varied among the species (Table 2), in parallel with the shoot number.

## ACKNOWLEDGEMENTS

This study was supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture, Japan.

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# ASSESSMENT OF WEED DENSITIES IN SPRING BARLEY BY IMAGE ANALYSIS

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*Summary:* An automatic weed density estimator method is proposed, based on a non-linear regression model and features of the plant segments in an image. The method is applied to a set of images from five barley fields. At present two features of the segment are used: segment area and whether a segment cuts the image border. A method is suggested for evaluating the automatic weed density estimator by comparison with an interactive weed density estimator including human judgement. Critical factors and ways of improving the automatic method by including additional feature are discussed.

*Keywords*: image processing, patchiness, remote sensing

## INTRODUCTION

Herbicides are normally applied to the entire field with the same dose although weeds usually occur in patches. One way to reduce use of herbicides, and thereby reduce their unwanted side-effects, could be only to apply herbicides to areas, where the weed density exceeds the economic threshold, and differentiate herbicide doses depending of the density of weeds. Recent development in sensor and spray technology, combined with powerful low cost computers, may make it possible to use automatic selective spraying technique in the future (2, 5). Estimation of weed densities by sensors are, however, difficult and technological problems need to be solved before automatic selective herbicide application can be implemented. The aim of this paper is to describe an automatic method, which is under development, to estimate weed density under field conditions. The method consists of identification of plant segments in an image and a non-linear statistical model to estimate weed density based on properties of these segments (for a detailed description see (1)).

## MATERIALS AND METHODS

The main steps in image processing and the statistical analysis are (i) image acquisition; (ii) identification of vegetation pixels; (iii) image segmentation to find plant segments, i.e. sets of connected pixels corresponding to plants or plant parts; and (iv) estimation of number of weed plants in each plant segment based on the features related to size, share texture and colour of the segment. The image acquisition consists of photography and scanning. From each of five barley fields, 20 colour photographs of crop and weed were taken during the period 13-22 May 1992. On these photographs, 32 weed species were recorded. A map of each photographed area was drawn in the field and all plants were marked on the map. The photographs were taken with a Canon EOS 100 camera placed on a stand pointing directly towards the ground with the end of the lens 70 cm above the ground. The ground area for each photograph was 14.7x22 cm. From each of the 24x36 mm photographic negatives, 10x15 cm colour prints were made and scanned at 300 dots per inch by an Agfa Arcus-colour scanner resulting in digital images with approximately 1200 x 1800 pixels. One pixel correspond to 0.123x0.123 mm ground surface.

From the colour image (Fig. 1a) we proceed by transforming to a grey level image (Fig. 1b). A preliminary classification of pixels is made, based on whether the grey level exceeds a certain threshold or not (1). This threshold technique seems to separate plants and soil pixels reasonably well (Fig. 1c). To describe plants as objects we try to restore plant segments from the thresholded image. As plant segments close to each other often belong to the same plant we have developed an automatic procedure to connect segments (1). In many cases the segments have been separated in the thresholded image because of variation in colour and light reflection. Isolated plant pixels are removed and hole in the segments are filled in by use of erosion and dilation imaging techniques (4). The results of the automatic

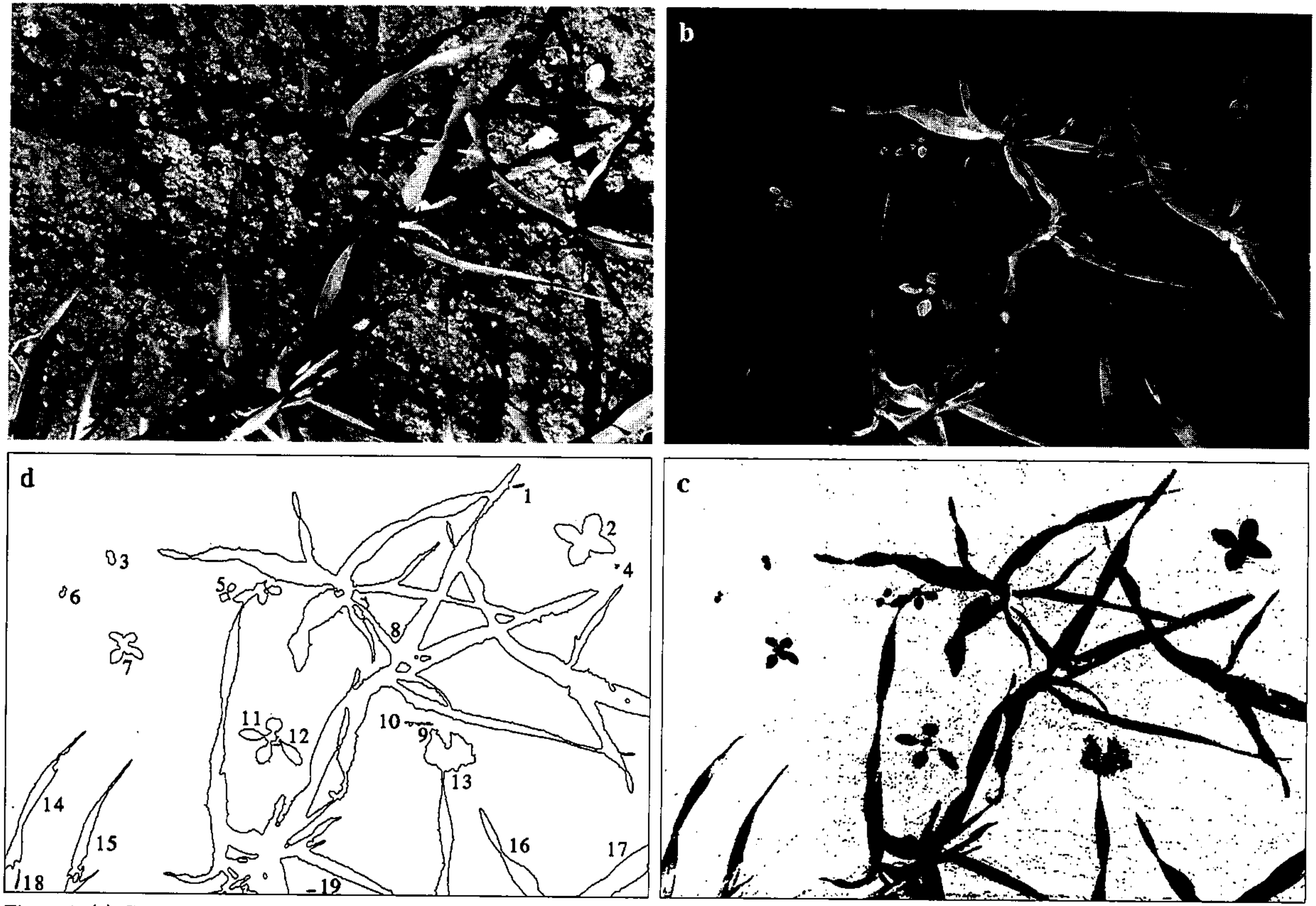


Figure 1. (a) Green component after scanning of one of the colour photographs; (b) corresponding grey level after transformation; (c) black and white image after thresholding; (d) segmented image.

segmentation procedure is shown in Fig. 1d. The next step is to estimate weed density from this image. An interactive and an automatic weed density estimator are suggested. Both are quotients between an estimate of the number of weed plants with their centroid not covered by crop and an estimate of the area not covered by crop in the image.

*Interactive estimation methods*: The suggested interactive estimator for the expected number of weed plants per unit area from image *i* is:

$$\bar{\mu}_i = \frac{N_i}{A_i - C_i} \qquad (I)$$

where $N_i$ is the number of weed plants in the image *i* with centroid inside frame and outside the area covered by crop (e.g. Fig. 1 segment 1, 2, and 3) , $A_i$ denotes the total area of image *i*, and $C_i$ denotes the area of image *i* covered by crop. The variables $N_i$ and $C_i$ , and thus also the estimate $\mu_i$ are best determined by an interactive method using both observer judgment and image analysis. A subjective scoring procedure was used to estimate the crop area $C_i$ based on measurements of segment areas obtained by image analysis.

*Automatic estimation*: For the automatic method the crucial quantity is the estimate of the number of weed plants not covered by crop. This estimate is a sum over all segment in the image: each segment gives a contribution to the sum that depends on the features of the segment. At present two features are used: segment area and whether a segment cuts the border or not. The number of weed plants in an image *i* is defined as

$$N_i = N_i 0 + \sum_{j=1}^{n_i} N(S_{ij}) \qquad (II)$$

where $N(S_{ij})$ denotes the number of weed plants in segment $S_{ij}$ such that the weed plants centroid is both inside image frame and is not covered by crop, and $N_{i0}$ is the number of weed plants not associated with any segment (plants lost in the segmentation procedure). The estimation of $N(S_{ij})$ is crucial in the automatic density estimation method. For each segment we record: the total area (in pixel) of segment $S_{ij}$, length (in pixels) of perimeter of segment $S_{ij}$, and length (in pixels) of the perimeter common with image border for segment $S_{ij}$. If a weed plant had parts in several segments it was counted only for the segment with the largest weed plant part. The relation between the number of weed plants $N(S_{ji})$ and $\log_e A(S_{ij})$ was obtained by regression (1). Separate analysis were made for inner segments not cutting the image border and border-cutting segments. For the image-wise analysis of weed number and crop area we also used regression models (for a detailed description see (1)).

For the automatic estimation of crop area $C_i$ within an image *i* we used a regression model based on the sum of the area of individual segments in the image (1). If we let $\hat{N}_i$ and $\hat{C}_i$ denote predicted values obtained we suggest the following automatic estimator of the weed density in image *i*:

$$\hat{\mu}_i = \frac{\hat{N}_i}{A_i - \hat{C}_i} \qquad (III)$$

## RESULTS AND DISCUSSION

The interactive weed density estimator was used as a standard against which the automatic estimator was evaluated. The automatic crop area estimator $\hat{C}_i$ was found to be satisfactory (empirical correlation coefficient between the logarithms of the interactive and the automatic crop area estimator was 0.93). The present automatic weed number estimator was not satisfactory (correlations coefficient between observed ($N_i$) and estimated values of ($N_i$) was r=0,57). Similarly the resulting automatic weed density estimator was unsatisfactory (Fig. 2). There are several possibilities for improving the automatic weed number estimator. The present version is based on only 2 features of each segment, segment size and being border-cutting or not. The number of weed plants associated with a segment is clearly correlated with the size of the segment, although there is considerable residual variation (1). The response curves for inner and border-cutting segments are also quite different (1). Thus the two feature are useful for estimating the number of weed plants associated with each segment. Petersen (3), who studied the identification of weed seeds by image processing, found that for a data set with 40 species, the identification probability, increased up to the use of 25 features. Inclusion of additional features of segments should be used in further investigation. These may include colours and texture within the segment and in particular, the properties of their contours. Some weed species tend to have reddish hypocotyl, stalks and reddish shoots between the cotyledons (e.g. *Stellaria media, Polygonum* spp. and *Geranium* spp.). At present we are unable to detect the reddish parts in the segmentation method and this can result in separation of a seedling into several segments (e.g. Fig. 1c, segment 11 and 12). Under pronounced humid conditions with high incidence of green moss and algae, our present segmentation methods may produce a large number of small spurious segments with a typical ragged contour. It should be possible to modify our estimators for the number of weed plants by identifying these segments as algae and moss and eliminate them from the estimation procedure. Features of contours may also allow estimates of weed densities for individual species in the future. We expect that the basic approach with assessment of weed densities by use of estimators such as (I) and (III) should remain valid.

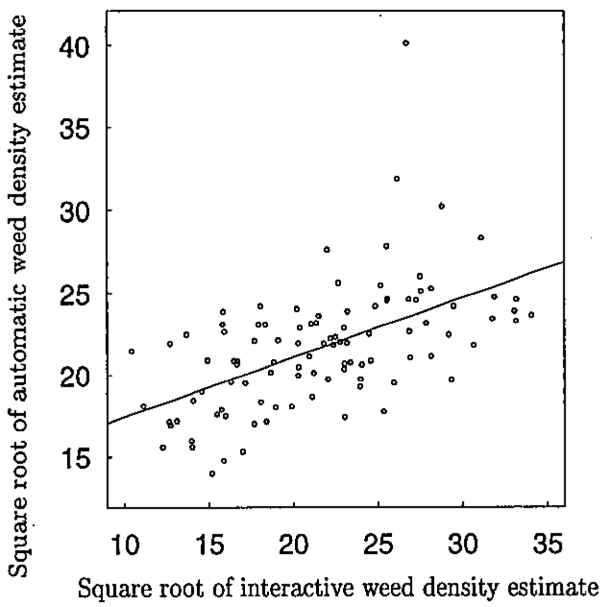


Figure 2. Plot of the square root $(\bar{\mu}_i)^{1/2}$ of the automatic weed density estimate (number of weed plants per square metre)$^{1/2}$ versus the square root $(\hat{\mu}_i)^{1/2}$ of the interactive weed density estimate (number of weed plants per square metre)$^{1/2}$ for the full set of 100 images.

Thompson *et al.* (5) found that in the few weeks after emergence, the growth of an autumn-sown crop will prevent weeds from being detected in 60-90% of the fields. For the present data set, obtained during a 10-day period, we found that weed density estimation was more difficult for images obtained during the last five days. Thus time of image acquisition is critical. By keeping some rows unsown, or by increasing crop row distances in the field, it should be possible to improve the automatic estimation procedure considerably by focusing on an area between crop rows and thereby reducing the interference of the crop. To avoid yield loss the density of crop plants in the rows should be increased to counterbalance increasing row distances. The steady improvement of cameras and computer hardware will make it easier to improve segmentation and to reduce the computation time and increase the prospect for a computer based system to measure weed densities in real-time.

## ACKNOWLEDGEMENTS

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# REVISION OF THE GENUS *MONOCHORIA* IN ASIA

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*Summary*: The species and variety of the genus *Monochoria* distributed in Asia were revised by studying herbarium specimens, individual plants from wild populations and also in cultivation experiments of accessions collected from various locations in Asia. As a result of this study, it was clarified that five species and one variety of the genus *Monochoria* are present in Asia. They are *Monochoria korsakowii* Regel et Maack, *M. hastata* (L.) Solms-Laubach, *M. elata* N. H. Ridley, *M. valida* G. X. Wang et H. Nagam., *M. vaginalis* (Burm.f.) Kunth var. *vaginalis* and *M. vaginalis* (Burm.f.) Kunth var. *angustifolia* G. X. Wang, T. Kusanagi et K. Itoh. Among these, *M. vaginalis* var. *angustifolia* is a new variety, an annual, emergent aquatic plant occurring in rice-fields of Thailand.

*Keywords*: *Monochoria*, *Monochoria vaginalis*, Pontederiaceae

The genus *Monochoria* (Pontederiaceae) consists of 9 species (Wang and Nagamasu, 1994) of conspicuous-flowered, emergent, aquatic plants with rhizomatous or stoloniferous stems distributed in tropical to warm Africa, Asia and Australia, naturalized in Europe. Like many aquatic plants, *Monochoria* shows extreme plasticity of many characters which, at times, obscures the clear delimitation of species (1, 2).

Kunth (4) recognized 8 species of *Monochoria* from Asia, viz. *Monochoria hastaefolia, M. sagittata, M. dilatata, M. vaginalis, M. ovata, M. plantaginea, M. loureirii* and *M. pauciflora*. Solms-Laubach (8) treated *M. plantaginea* and *M. korsakowii* as varieties of *M. vaginalis*, viz. *M. vaginalis* var. *plantaginea* and *M. vaginalis* var. *korsakowii*. He recognized 2 species and 2 varieties of *Monochoria* from Asia, and listed 3 synonyms for *M. hastata*, 1 synonym for *M. vaginalis* and 6 synonyms for *M. vaginalis* var. *plantaginea*. Cook (1) listed 21 synonyms for *M. vaginalis* and 7 synonyms for *M. hastata*. He recognized 4 species of *Monochoria* from Asia, viz. *M. korsakowii*, *M. vaginalis*, *M. hastata* and *M. elata*.

In order to provide a solution to such disagreements, we have examined a number of specimens kept in FU, HIB, HIMC, IBSC, IFP, KUN, KYO, MAK, NEFI, PE, SAP, SAPA, SYS, TI, TNS, TUS, WH, YUKU, and Research Institute for Bioresources, Okayama University, and those collected by ourselves in the field, observed 23 wild populations from pools, ditches, canals and rice-fields in China and Japan, and carried out cultivation experiments in the Experimental Plot of the Faculty of Agriculture, Kyoto University, Japan. The seeds and young plants used in the cultivation experiments were collected from China, Korea, Malaysia, Thailand, Vietnam and throughout Japan.

Key to the species of *Monochoria* in Asia

1a) Inflorescen ce panicle-like (lower branches 2-4 flowers ); seeds cylindrical, 1.2-2.0 mm long 1. *M. korsakowii*
1b) Inflorescence racemose or sub-umbellate; seeds globose, ovoid to nearly cylindrical, 0.5-1.2 mm long.
2a) Inflorescence sub-umbellate 2. *M. hastata*
2b) Inflorescence racemose.
3a) Mature blades sagittate or hastate.
4a) Mature blades slightly narrowed, 0.8-2.5 cm wide, basal lobes 0.9-3.0 cm long---------------------- 3. *M. elata*
4b) Mature blades broad,10-20cm wide, basal lobes 5-11 cm long--------------------------------------- 4. *M. valida*
3b) Mature blades ovate, cordate or reduced, narrowly lanceolate.
5a) Mature blades broad, ovate or cordate, the widthlength 0.5-0.95---------------- 5a. *M. vaginalis* var. *vaginalis*
5b) Mature blades reduced, narrowly lanceolate, the widthlength 0.1-0.4 (-0.5) ---- *M. vaginalis* var. *angustifolia*

1. *M. korsakowii* Regel et Maack (1861).

Annual, (12-) 40-80 (-90) cm high; main stem erect and short, 5-15 cm long; tillering stems elongate and creeping, 10-50 cm long and 0.3-2.2 cm in diameter, with numerous adventitious roots. Radical leaves either linear, submerged, ephemeral and absent at anthesis or differentiated into petiole with blade, floating and ephemeral or emergent; petioles (6-) 10-45 (-50) cm long, bright purple below; stipules 4-15 cm long and the terminal appendages 1-6 cm long; blades usually cordate, rarely lanceolate or ovate-cordate, (2.5-) 5-13 (-15) cm long, (0.5-) 1.5-12 (-15) cm wide; basal lobes

(0-) 0.5-2 (-3) cm long. Inflorescence terminal, panicle-like, with (2-) 10-30 (-55) flowers, the lower branch bearing 2-4 flowers; flowerless part of the inflorescence (2-) 5-13 cm and flower bearing part of the inflorescence 5-19 cm long; inflorescence stalks erect and emergent, (5-) 15-35 (-50) cm long; sheath of the lower spathe (1.5-) 2-5 (-6.5) cm long; petiole of the lower spathe (1-) 3-13 (-15) cm long; blades of the lower spathe cordate, (1.5-) 3-13 (-16) cm long, (0.8-) 2-12 (-15) cm wide; sheath of the upper spathe (2.5-) 3-7 (-8) cm long; blade of the upper spathe often linear or even filamentous, rarely cordate or ovate; perianth-segments purplish blue, 1.4-2.2 cm long, the three exterior narrower, (0.4-) 0.5-0.7 (-0.9) cm and the three interior broader, (0.6-) 0.8-1.2 (-1.35) cm wide; 6 stamens, 5 small and 1 large; the small ones with simple, 3-6 mm long filaments and yellow, 2-3.5 mm long anthers; the large one with an appendaged, 4-6.5 mm long filament and a purplish blue, ( 3.2- ) 4-5 mm long anther; pistil approximately as long as large stamen, style bent, opposite large stamen. Capsules ovoid-conical. Seeds cylindrical, (1.0-) 1.2-2.0 mm long, 0.5-0.8 mm in diameter, with 9-11 narrow, longitudinal ribs.

Note: *Monochoria korsakowii* is a species of eastern Asia (1). For the past several decades, the region of the distribution in China gradually has been reduced northward. In Japan, *M. korsakowii* was widely distributed from Hokkaido to Kyushu before according to literature (3, 6) and herbarium specimens, but, at present, it is distributed only from Hokkaido to Okayama according to our survey. Because of the continuous uses of herbicides, exploitation of marshy ground, and that rivers and waterways have been channelized with concrete, *M. korsakowii* has disappeared from Kumamoto, Tokushima, Kochi and Yamagochi, Hiroshima in Japan and SW China (10).

2. *Monochoria hastata* (L.) Solms-Laubach (1883)

Perennial, (30-) 60-120 (-135) cm high; stems rhizomatous, often long and strong, with numerous adventitious roots, clothed with the remains of old sheaths. Radical leaves either linear, submerged, ephemeral and absent at anthesis or differentiated into petiole with blade, emergent; petioles (25-) 40-60 (-75) cm long, bright purple below; stipules 10-25 cm long and the terminal appendages 5-10 cm long; blades hastate, (5-) 10-19 cm long, (4.5-) 8-12 (-15) cm wide; basal lobes (1.5-) 2-5 (-6) cm long. Inflorescence sub-umbellate, with (10-) 30-50 (-60) flowers; flowerless part of the inflorescence 1-1.8 cm and flower bearing part of the inflorescence 4-6 cm long; inflorescence stalks erect or suberect and emergent, (25-) 45-60 (-70) cm long; sheath of the lower spathe (2-) 4-6 cm long; petiole of the lower spathe (4-) 7-10 (-13) cm long, erect; blades of the lower spathe hastate, emergent, (5-) 10-18 (-20) cm long, (4-) 6-10 (-13) cm wide; sheath of the upper spathe membranous, (2-) 3-5 (-6) cm long, without petiole and blade; perianth-segments *ca.* 1.7 cm long, the three exterior narrower, *ca.* 0.6 cm wide and the three interior broader, *ca.* 0.9 cm wide; 6 stamens, 5 small and 1 large; the small ones with simple, *ca.* 3 mm long filaments and yellow, *ca.* 4 mm long anthers; the large one with an appendaged, *ca.* 5 mm long filament and a purplish blue, *ca.* 6 mm long anther; pistil approximately as long as large stamen, style bent, opposite large stamen. Capsules ovoid *ca.* 12 mm long, *ca.* 9 mm diameter. Seeds ovoid to barrel-shaped, 0.7-0.9 mm long, 0.4-0.6 mm diameter, with 9-12 narrow, longitudinal ribs.

3. *Monochoria elata* N. H. Ridley (1918)

Perennial, (100-) 150-220 (-260) cm high; stems rhizomatous, with numerous adventitious roots. Leaves radical; petioles erect, up to 140 cm long; stipules 25-40 cm long and the terminal appendages 15-30 cm long; blades reduced, linear with an auriculate base, to elongate-hastate, (10-) 15-30 (-35) cm long, 0.8-2.5 cm wide, slightly narrowed to the tip; lobes at base *ca.* 2.0 cm long, up to 1 cm wide. Inflorescence racemose, with 15-40 flowers; flowerless part of inflorescence 0.8-2.0 cm and flower bearing part of inflorescence (7-) 10-15 (-18) cm long; inflorescence stalks erect and stiff, (50-) 90-150 (-190) cm long; sheath of lower spathe 4-10 cm long; petiole of lower spathe (5-) 15-25 (-30) cm long, erect and stiff; blades of lower spathe elongate-hastate or elongate-sagittate, (5-) 8-15 (-18) cm long, (0.25-) 0.8-1.5 (-2.0) cm wide, lobes at base *ca.* 1.5 cm long or blade narrowly triangular, up to 15 cm long and 1.2 cm wide near base; sheath of upper spathe approximately as long as sheath of lower spathe, membranous, without petiole and blade; perianth-segments *ca.* 1.6 cm long, the three exterior narrower, *ca.* 0.5 cm and the three interior broader, *ca.* 1.0 cm wide, persistent and twisted around the fruit; 6 stamens, 5 small and 1 large; the small with simple, *ca.* 3.0 mm long filaments and yellow, *ca.*5.0 mm long anthers; the large with an appendaged, *ca.* 4.5 mm long filament and a purplish blue, *ca.* 10 mm long anther; pistil approximately as long as large stamen, style bent, opposite large stamen. Fruit oblong, *ca.* 11 mm long, *ca.* 7.0 mm diameter. Seeds ovoid, *ca.* 0.7 mm long, *ca.* 0.45 mm diameter, with 10-12 narrow, longitudinal ribs.

4. *Monochoria valida* G. X. Wang et H. Nagam. (1994)

Perennial, 130-210 cm high; stems rhizomatous 2-4 cm in diameter, with numerous adventitious roots. Radical leaves distichous; petioles erect, 110-170 cm long; stipules *ca.* 55 cm long and the terminal appendages up to 30 cm long; blades sagittate, 20-35 cm long, 10-15 cm wide; basal lobes (5-) 7-11 cm long, 4-7 cm wide. Inflorescence racemose, with 50-110 flowers; flowerless part of inflorescence 1.5-3.5 cm and flower bearing part of inflorescence 10-20 cm long; inflorescence stalks erect, slightly grooved, 110-200 cm long; sheath of lower spathe 5-7 cm long; petiole of lower spathe 4-8 cm long; blades of lower spathe sagittate, 18-28 cm long, 4-10 cm wide; basal lobes (3-) 4-10 cm long; sheath of upper spathe 6-8 cm long, without petiole and blade; perianth-segments purplish blue, *ca.* 1.6 cm long, three exterior narrower, *ca.* 0.6 cm wide, three interior broader, *ca.* 1.0 cm wide, persistent and twisted around fruit; stamens of 2 kinds, 5 with simple, *ca.* 3.0 mm long filaments and yellow, *ca.* 4.0 mm long anthers; 1 with an appendaged, *ca.* 5.0 mm long filament and a purplish blue, *ca.* 7.0 mm long anther; pistil approximately as long as large stamen, style bent, opposite large stamen. Fruit oblong, *ca.* 12 mm long, *ca.* 8.0 mm diameter. Seed sovoid, *ca.* 0.75 mm long, *ca.* 0.5 mm in diameter.

5a. *Monochoria vaginalis* var. *vaginalis* (Burm. f. ) Kunth (1843)

Annual, 10-60 (-90) cm high; main stem erect and short, 1-5 cm long, tillering stems elongate and creeping, up to 30 cm long, both with numerous adventitious roots; rarely rhizomatous. Radical leaves either linear, submerged, ephemeral and absent at anthesis or differentiated into petiole with blade, floating and ephemeral or emergent; petioles (5-) 10-45 (-70) cm long, bright purple below; stipules 2-12 cm long and the terminal appendages 1-7 cm long; mature blades ovate-cordate or cordate, rarely lanceolate, (3-) 4-9 (-15) cm long, (1.5-) 2-8 (-14) cm wide; the width/length 0.5-0.95; basal lobes up to 2 cm long. Inflorescence usually shortly racemose, becoming strongly deflexed in fruit, with (2-) 3-10 (-30) flowers, occasionally branched below but branches bearing not more than 2 flowers; flowerless part of the rachis 0.4-1.5 cm and flower-bearing part of the inflorescence 1.0-4.5 cm long; inflorescence stalks emergent, (3-) 5-25 (-40) cm long; sheath of the lower spathe (1.5-) 2-5 (-6) cm long; petiole of the lower spathe (2-) 3-10 (-22) cm long; blades of the lower spathe ovate-cordate or cordate, (2.5-) 5-10 (-12) cm long, (1.5-) 2-8 (-11) cm wide, often longer than wide; sheath of the upper spathe *ca.* 1/4 shorter than sheath of the lower spathe; blade of the upper spathe often filamentous, rarely linear to cordate; internode between the spathes 0.5-1.5 cm long, strongly deflexed in fruit; perianth-segments purplish blue, green central veins particularly distinct and persisting, 1.0-1.2 cm long, the three exterior narrower, 0.3-0.5 cm wide, the three interior broader, 0.5-0.7 cm wide; stamens of 2 or 3 kinds; 5 small and 1 large, or 4 small,1 large and 1 intermediate; the small ones with simple, 2-4 mm long filaments and yellow, 1-2 mm long anthers; the intermediate one with simple, 3-5 mm long filament and yellow, 1-2 mm long anther; the large one with an appendaged, 3-5mm long filament and a blue, 2-3.5 mm long anther. Capsules ellipsoidal to ovoid. Seeds ovoid to barrel-shaped, 0.5-1.2 mm long, 0.3-0.6 mm diameter, with 10-14 narrow, longitudinal ribs.

5b. *Monochoria vaginalis* (Burm. f. ) Kunth var. *angustifolia* G. X. Wang, T. Kusanagi et K. Itoh, var. nov. Fig. 1

Diagnosis: A var. vaginalis recedit foliis anguste lanceolatis, 3-7 cm longis, 0.3-2.0 cm latis, apice acutis vel acuminatis, racemis 3-7 floris.

Holotype: THAILAND NE. Prov. Mahasarakarm: Koksung District (Sept. 18, 1984 N. Fukuoka T-36166 KYO).

Annual, 10-30 cm high, main stem erect and short, 1-3 cm long, tillering stems elongate and creeping, up to 20 cm long, both with numerous adventitious roots; rarely rhizomatous. Radical leaves either linear, submerged, ephemeral and absent at anthesis or differentiated into petiole with blade, floating and ephemeral or emergent; petioles 6-20 cm long, bright purple below; stipules 2-4 cm long and the terminal appendages 0.6-2.5 cm long; mature blades reduced, narrow lanceolate, 3-7 cm long, 0.3-2.0 cm wide; the width/length 0.1-0.4; basal lobes 0-2 mm long. Inflorescence usually shortly racemose, becoming strongly deflexed in fruit, with (2-) 3-7 flowers; flowerless part of the rachis 0.5-1.5 cm and flower-bearing part of the inflorescence 1.0-2.5 cm long; inflorescence stalks 2.5-10 cm long; sheath of the lower spathe 1.5-2.5 cm long; petiole of the lower spathe 2-6 cm long; blades of the lower spathe lanceolate, 4-7 cm long, 0.4-2.0 cm wide; sheath of the upper spathe *ca.* 1/4 shorter than sheath of the lower spathe; blade of the upper spathe often filamentous, rarely linear; internode between the spathes 0.5-1.0 cm long, deflexed in fruit; perianth-segments purplish blue, green central veins particularly distinct and persisting, 1.1-1.2 cm long, the three exterior narrower, *ca.* 0.4 cm and the three interior broader, *ca.* 0.6 cm wide; stamens of 3 kinds; 4 small, 1 large and 1 intermediate; the small ones with simple, *ca.* 2 mm long filaments and yellow, *ca.* 1 mm long anthers; the intermediate one with simple, *ca.* 3 mm long filament and yellow, *ca.* 1mm long anther; the large one with an appendaged, *ca.* 3 mm long filament and a blue, *ca.* 2 mm long anther. Capsules ellipsoidal. Seeds ellipsoidal, *ca.* 1 mm long, *ca.* 0.6 mm diameter, with 10-11 narrow, longitudinal ribs.

Other specimens examined: THAILAND Krungtep: Phra Nakhon (Nov. 1965 N. Tagawa et al T280 KYO), Sisaket: near Kantharalak (Oct. 1984 G. Murata et al T-49700 KYO), Ubon Rachathani: Ubon Rachathani city (Oct. 1984 G. Murata et al T-52165 KYO).

Table 1. Comparison between *M. vaginalis* var. *vaginalis* and *M. vaginalis var. angustifolia*

| Character | *M. vaginalis* var. *vaginalis* | *M. vaginalis* var. *angustifolia* |
|---|---|---|
| Leaf shape | Broad, ovate or cordate | reduced, narrowly lanceolate |
| Leaf size | 4-9 cm x 2-8 cm | 3-7 cm x 0.-32 cm |
| Basal lobe length | < 20 mm | < 2 mm |
| Width/length of radical leaf | 0.5-0.95 | 0.1-0.4 |
| Dry weight per fruit | 29.76 (±4.35) mg | 13.97 (±4.03) mg |
| Number of seed per fruit | 139.98 (±18.19) grains | 68.00 (±19.61) grains |
| Dry weight of seed per fruit | 21.84 (±3.52) mg | 9.41 (±3.03) mg |

Note: Variety *angustifolia* can be distinguished clearly from the type variety of this species by morphological characters (See Table 1) and chromosome numbers (10). In var. *angustifolia*, the mature blades are reduced, narrow lanceolate, 3-7 cm long, 0.3-2.0 cm wide, the width/length 0.1-0.4, basal lobes 0-2 mm long, while in var. *vaginalis*, the mature blades are ovate-cordate or cordate, 4-9 cm long, 2-8 cm wide, the width/length 0.5-0.95, basal lobes up to 2 cm long. Moveover, we measured the dry weight per fruit, number of seeds per fruit and dry weight of seeds per fruit of 40 samples. In var. *angustifolia*, the mean dry weight per fruit is 13.97 mg, the mean seed number per fruit is 68 grains and the mean dry weight of seed per fruit is 9.41 mg, while in var. *vaginalis*, the mean dry weight per fruit is 29.76 mg, the mean seed number per fruit is 139.98 grains and the mean dry weight of seed per fruit is 21.84 mg.

In Cook (1), *Monochoria linearis* Miq. where the leaves were linear was thought to be a synonym of *M. vaginalis*. But Miquel (5) thought it was probable that *M. linearis* did not belong to the genus *Monochoria* because of " umbellae pauciflorae erectae ". From the viewpoint of " umbellae pauciflorae erectae ", we thought *M. linearis* is different from *M. vaginalis* var. *angustifolia*.

Fig. 1. *M. vaginalis* var. *angustifolia* G. X. Wang, T. Kusanagi et K. Itoh, var. nov. (*N. Fukuoka T-36166*, Type)

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# OVERSUMMERING RULES OF WILD OATS IN RICE-WHEAT DOUBLE CROPPING FIELDS IN JIANGSU PROVINCE OF CHINA

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*Summary*: This research was conducted from1993 to 1995 to study the oversummering rules of wild oat (*Avena fatua* L.). Two ecotype seeds were used, W-DAS (from wheat plants of rice-wheat double cropping) and D-DAS (from wheat plants of dryland). The dormant period of W-DAS was related to the site of seed on ear and the presence or absence of lemma and palea. The death rate of W-DAS was about 70% in the rice, 20%lower than that of D-DAS, due to the higher ABA/GA ratio and lower 1000-grain weight of W-DAS.

*Keywords*: wild oats; oversummering; rice-wheat double cropping

## INTRODUCTION

Wild oat (*Avena fatua* L.) is an annual grass. It is widely distributed and does great damage in dryland such as wheat, barley and rape fields. It was reported that wild oat seeds would have thoroughly lost their germination ability after being buried 10-20 cm deep in rice field soil for 37 days, and that water-dry continuous cropping or rotated cropping could effectively control the emergence of wild oat. Jiangsu province is an agricultural region where water-dry continuous cropping (rice-wheat-rice) is widespread. Since 1986, wild oat has been spreading in this region and causing increasing damage year by year. To find out the reason why wild oat spreads among wheat plants of rice-wheat double cropping, we carried out the study on dormancy and oversummering rules of wild oat in rice-wheat double cropping from 1994 to 1995.

## MATERIALS AND METHODS

Wild oat seeds of two ecotypes were used. One ecotype was from the wheat field of rice-wheat double cropping of more than five consecutive years (called W-DAS below), which were collected from Chengjiao Town of Baoying County and the other ecotype was from the wheat field of dryland of more than five consecutive years (called D-DAS below), which were collected from Sheyang Town of Baoying County.

Investigation of perpendicular distribution rule and death rate of W-DAS in rice field soil: After harvesting, the total amount and amount of dead wild oat seeds in different soil strata were examined. For this experiment ten representative fields were chosen, and within each of them five spots with an area of 0.56 square meter were examined. Comparison between the two ecotype wild oat seeds for their oversummering rules in different environment were as follows:

Seed ecotype: W-DAS ; D-DAS.
Site of seed on ear: base position ; upper position
Lemma and palea: present; absent
Oversummering environment: room; dry land, 5-10 cm deep; rice field, 5-10 cm ; deep and soaked in water.

There were 32 treatments in total as described above. Each treatment used 16 gauze bags filled with 100 wild oat seeds, and each was repeated 3 times. Determination of the germination rate, death rate, ABA and GA quantity of the seeds were carried out every 15 days. The quantity of ABA and GA were determined using ELISA.

The laboratory experiments were conducted of the Institute at Plant Protection, Jiangsu Academy of Agricultural Science. The field experiments were conducted in the experiment fields of Science and Technology Commission of Baoying County.

## RESULTS AND DISCUSSION

*Perpendicular distribution rule and death rate of wild oat seeds in rice field soil*: According to the investigation in Oct. 1994, the total amount of wild oat seeds on 0.56 square meter was 1801, with 43.9% within the stratum 5-10 cm deep, 17.8% within the stratum 10-15 cm deep and 2.7% within the 15-20 cm deep stratum. The death rates of the wild oat seeds within these stratums were 86.8%, 78.6%, 67.4% and 23.5% respectively. This suggested that there existed great differences between the wild oat seeds distributed within the soil strata at different depths. The deeper the seeds were distributed, the lower the death rate.

*The relationship between the dormancy and size of wild oat seeds*: At maturity, the seeds coming from different position on ear had different size, the seeds from basal position were bigger than those from the upper position. And the experiment showed that the dormant period of large seeds was shorter than that of small seeds.

*The relationship between the dormancy and the lemma and palea of wild oat seeds*: The lemma and palea of wild oat seeds could remarkably lengthen their dormant period. On maturing, the germination rate of the wild oat seeds without lemma and palea was 8%, After being hung in the room for 15 days, the germination rate reached to 85%. The seeds with lemma and palea, after being hung for 15, 30, 45 days, gave germination rates of 7%, 15% and 40% respectively. Oversummered, the germination rate of the seeds without lemma and palea was 98-100%, while the ones with lemma and palea only had a germination rate of 65%.

*The relationship between the dormancy of wild oat seeds and their oversummering environment*: Wild oat seeds were put in soil of ricefield or dryland (maize field) 5-10 cm deep, or stored in airing room. Germination rates were determined every 15 days. The results indicated that seeds under different environment had different dormant periods. Those hung in rooms had the shortest dormant period, followed by the seeds in dryland, while the seeds in rice fields had the longest dormant period. (Table 1).

Table 1. The germination percentage of wild oat seeds in different environments during and after summer (%)

| Environment | Date (month/day) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 6/1 | 6/15 | 7/1 | 7/15 | 8/1 | 8/15 | 9/1 | 9/15 | 10/1 |
| In room | 0 | 7 | 15 | 40 | 48 | 45 | 56 | 60 | 79 |
| Dry land | 0 | 0 | 0 | 8 | 13 | 18 | 21 | 54 | 66 |
| Rice field | 0 | 0 | 0 | 2 | 5 | 7 | 47 | 40 | 51 |

*Oversummering death rate of wild oat seeds in different environment*: At different environmental situation, the oversummering death rate of W-DAS was different as well. Seeds in the soil of ricefields soaked in water, ricefield, dryland and in the room through the summer had death rates of 100%, 73.2%, 7.8% and 0 % respectively. Clearly the ones in water soaked ricefields had the highest death rate.

*Comparison between the oversummering death rates of the two ecotypes of wild oat seeds*: Both D-DAS and W-DAS were put in rice field or dryland soil, and their death rates were determined. The result showed that the oversummering death rates of D-DAS and W-DAS in dryland soil were similar to each other. but in the rice field, the death rates were quite different. After oversummering in ricefield for 30 days, the death rate of D-DAS increased quickly for 45 days, and reached 50% at day 60. Death rate reached more than 75%, after the summer (the death rate was 94%). As to W-DAS, oversummered in rice field for 60 days, its death rate was 8%, for 70 days, the death rate increased. After summer, it reached 73%. From this result, it was concluded that the oversummering rate of W-DAS was 20% lower than that of D-DAS.

*Physiological reason for the low oversummering death rate of W-DAS in rice field*: The oversummering death rate of W-DAS in rice field was much lower than that of D-DAS. The main reason was that the dormancy of W-DAS was deeper than that of D-DAS. The 1000-grain weight of W-DAS was heavier than that of D-DAS. According to the result from the germination test of wild oat seeds, the lighter the 1000-grain weight, the deeper the dormancy, and the longer the dormant period. The 1000-grain weight of W-DAS was 17.70 g, which was much lighter than that of D-DAS (21.07g). This suggested the dormancy of W-DAS was deeper than that of D-DAS. The ratio of endogenous hormones ABA to GA of W-DAS was higher than that of D-DAS. Dormancy and germination of seed are controlled by endogenous hormones. Growth inhibitor ABA can induce dormancy, but its activity is antagonized by growth promoter GA. Therefore, the quantity of ABA and GA and the ABA/GA ratio in seed can reflect the degree of dormancy. The higher the ABA/GA, the deeper the seed dormancy. Determination of the quantity of ABA and GA of wild oat seeds of the two ecotypes suggested that ABA/GA ratio of W-AS is 0.865/1 and of D-DAS is 0.515/1.

In conclusion, the dormant period of wild oat seeds in rice-wheat double cropping fields in Jiangsu was closely related to the seed size and the presence or absence of lemma as well as palea and the oversummering environment. The dormant period of the biotype with small seeds, with lemma and palea and oversummering in soil was longer than the large seeds, without lemma and palea and oversummering in the room.

In dryland soil, the oversummering death rate of W-DAS resembled that of D-DAS, but in the ricefield, the oversummering death rate of W-DAS was much lower than that of D-DAS. The reason was that the dormancy of W-DAS was deeper than D-DAS due to the lower 1000-grain weight and higher ABA/GA of W-DAS.

According to the morphology, biochemical index and response to different ecological environment, the wild oat seeds from the two ecological environments can be determined as being of two ecotypes

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# EFFECT OF SOIL FLOODING CONDITION AND SEEDING DEPTH ON EMERGENCE OF RICE FIELD WEEDS

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*Summary*: Under aerobic conditions critical emergence depth of *Echinochloa crus-galli* and *Aeschynomene indica* was 10 cm, while for weedy rice, and cultivated rice it was 7cm. Under flooded soil conditions there was no emergence at all at the 1 cm sowing depth. Under saturated conditions, emergence was delayed and much reduced for sowing depths of 1 cm or more for all species, while *A. indica* did not emerge. Emergence percentage of weeds and rice was lower with increase in seeding depth and redox potential. Plant height, number of leaves and dry weight of weed species were higher at low seeding depth.

*Keywords*: rice weeds, seeding depth, emergence

## INTRODUCTION

Planting of rice in Korea is expected to change from hand and machine transplanting to direct seeding because of socio-economic changes: decreasing availability of farm labor, increasing farm wages, increasing mechanization, and production of rice beyond national self-sufficiency. These factors are encouraging development of labor-saving and cost-reducing production technology. In 1995, the acreage of direct-seeded rice was 72,805 ha and this area will increase to about 700,000 ha by the year 2001, which is about 70% of the total rice area. But weed control is one of the most critical factors for successful production of direct seeded rice because weeds usually emerge faster than rice when soil is exposed during the initial growth stages of rice. Herbicide phytotoxicity also is more severe in direct-seeded than in transplanted rice, and the herbicides used should be safe to rice seedlings. Since weed emergence spans a long time in direct seeded rice, combinations of herbicides should be applied. These studies were conducted to investigate the influence of aerobic and anaerobic conditions on weed seed emergence and establishment.

## MATERIALS AND METHODS

Experiments were conducted to study critical sowing depth and redox potential under different soil moisture conditions at the International Rice Research Institute, Los Banos, Laguna, Philippines, in 1997. Weed species *Echinochloa crus-galli, Aeschynomene indica*, weedy rice and rice *var* Ilpumbyeo were used in these studies. Sowing depths studied were 0, 1, 3, 5, 7 and 10 cm and soil moisture conditions were aerobic, saturated and 3 cm flooding depth. Twenty-five seeds were sown in plastic trays (31x30x14 cm). After seeding, plants were maintained aerobic, saturated or under 3 cm water depth for 2 weeks. Germination percentage and redox potential was measured every day and growth of weeds and rice was measured at 15 days after seeding. The experimental design was a randomized complete block design with three replications.

## RESULTS AND DISCUSSION

Emergence percentage of weeds and rice under aerobic condition are shown in Table 1. Emergence percentage of *E. crus-galli* and *A. indica* were between 8-36% at the 10 cm seeding depth but weedy rice and cultivated rice did not emerge at all.

Table 1. Effect of seeding depth on emergence percentage of weed species and rice under aerobic condition

| Weed species and rice | Seeding depth | Days after seeding | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | 5 | 7 | 9 | 11 | 13 |
| *Echinochloa crus-galli* | 0 | 0 | 52 | 64 | 64 | 64 | 64 |
| | 1 | 0 | 60 | 64 | 72 | 72 | 72 |
| | 3 | 0 | 40 | 72 | 72 | 72 | 72 |
| | 5 | 0 | 40 | 60 | 60 | 64 | 64 |
| | 7 | 0 | - | 16 | 48 | 52 | 52 |
| | 10 | 0 | - | - | 12 | 36 | 36 |
| *Aeschynomene indica* | 0 | 0 | 88 | 92 | 96 | 96 | 96 |
| | 1 | 0 | 80 | 96 | 96 | 96 | 96 |
| | 3 | 0 | 40 | 80 | 92 | 92 | 92 |
| | 5 | 0 | 32 | 72 | 80 | 80 | 80 |
| | 7 | 0 | 28 | 68 | 76 | 76 | 76 |
| | 10 | 0 | 0 | 0 | 8 | 8 | 8 |
| Weedy rice | 0 | 0 | 84 | 92 | 92 | 92 | 92 |
| | 1 | 0 | 84 | 88 | 88 | 88 | 88 |
| | 3 | 0 | 68 | 88 | 88 | 88 | 88 |
| | 5 | 0 | 20 | 88 | 88 | 88 | 88 |
| | 7 | 0 | 0 | 28 | 52 | 52 | 52 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rice( Ilpumbyeo) | 0 | 0 | 68 | 72 | 76 | 76 | 76 |
| | 1 | 0 | 60 | 76 | 76 | 76 | 76 |
| | 3 | 0 | 12 | 56 | 56 | 64 | 64 |
| | 5 | 0 | 0 | 56 | 64 | 72 | 72 |
| | 7 | 0 | 0 | 8 | 12 | 12 | 12 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 |

On the other hand, at the 7 cm seeding depth, *E. crus-galli*, *A. indica* and weedy rice showed 2-76% emergence but rice had only 12% emergence. At the 0-5 cm seeding depth, weeds and rice showed no difference in emergence percentage but emergence percentage decreased as the seeding depth increased. The critical seeding depth for emergence of *E. crus-galli* and *A. indica* was 10 cm, whereas for weedy rice and rice it was 7 cm. At saturated soil condition, all weeds and rice did not emerge at all from below the 0 cm seeding depth (Table 2).

Table 2. Effect of seeding depth on emergence percentage of weed species and at saturated condition.

| Weed species and rice | Seeding depth | Days after seeding | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 3 | 5 | 7 | 9 | 11 | 13 | 15 |
| *Echinochloa crus-galli* | 0 | 0 | 16 | 52 | 68 | 80 | 84 | 84 |
| | 1 | - | - | - | - | - | 12 | 12 |
| | 3 | - | - | - | - | - | - | - |
| *Aeschynomene indica* | 0 | 4 | 32 | 48 | 52 | 52- | 60 | 60 |
| | 1 | - | - | - | - | - | - | - |
| | 3 | - | - | - | - | - | - | - |
| Weedy rice | 0 | 0 | 24 | 40 | 48 | 48 | 52 | 52 |
| | 1 | 0 | - | - | - | - | 8 | 12 |
| | 3 | - | - | - | - | - | - | - |
| Rice (Ilpumbyeo) | 0 | 0 | 28 | 44 | 52 | 52 | 60 | 60 |
| | 1 | - | - | - | - | - | 12 | 12 |
| | 3 | - | - | - | - | - | - | - |

Emergence data was well correlated with decrease in oxygen concentration with soil depth. The results indicate that, most weeds and rice emerge best in aerobic condition and at high oxygen concentrations.

Effect of seeding depth on emergence percent of weeds and rice under flooded condition are shown in Table 3. All weeds and rice showed high emergence percentage at the 0 cm seeding depth but did not emerge at all below the 0 cm seeding depth. This means that oxygen concentration of soil is very important for emergence of seeds. Arai and Miyahara (1) reported that the germination percentage of non-dormant *E. oryzicola* seeds decreased with decrease in oxidation-reduction potential, and there was no germination below Eh 6 at 100 mV. Plant height, number of leaves and dry weight per plant decreased as the seeding depth increased, but average days to emergence was delayed as seeding depth increased (Table 4).

Table 3. Effect of seeding depth on emergence percentage of weed species and rice under flooding condition.

| Weed species and rice | Seeding depth | Days after seeding | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 3 | 5 | 7 | 9 | 11 | 13 | 15 |
| *Echinochloa crus-galli* | 0 | - | 8 | 20 | 32 | 60 | 80 | 80 |
| | 1 | - | - | - | - | - | - | - |
| *Aeschynomene indica* | 0 | 12 | 16 | 16 | 16 | 20 | 20 | 20 |
| | 1 | - | - | - | - | - | - | - |
| Weedy rice | 0 | 0 | 16 | 28 | 44 | 60 | 92 | 72 |
| | 1 | - | - | - | - | - | - | - |
| Rice (Ilpumbyeo) | 0 | 0 | 24 | 36 | 48 | 60 | 92 | 72 |
| | 1 | - | - | - | - | - | - | - |

Table 4. Effect of seeding depth on characteristic of emergence and growth of weed species and rice at 17 days after seeding at saturated condition.

| Weed species and rice | Seeding depth | Emergence percentage | Av. days to emerge | Plant height | No. of leaves | Dry wt. mg/plant |
|---|---|---|---|---|---|---|
| *E. crus-galli* | 0 | 64 | 5.2 | 35.8 | 4.4 | 40 |
| | 1 | 72 | 5.4 | 37.3 | 5.4 | 45 |
| | 3 | 72 | 5.4 | 37.7 | 4.3 | 36 |
| | 5 | 64 | 6.3 | 34.7 | 4.2 | 34 |
| | 7 | 52 | 7.5 | 21.0 | 3.9 | 30 |
| | 10 | 36 | 8.3 | 19.0 | 3.0 | 21 |
| *A. indica* | 0 | 96 | 3.1 | 29.5 | 5.2 | 131 |
| | 1 | 96 | 3.3 | 28.0 | 5.1 | 120 |
| | 3 | 92 | 5.1 | 25.8 | 5.1 | 116 |
| | 5 | 80 | 4.7 | 21.3 | 4.5 | 71 |
| | 7 | 76 | 5.6 | 14.5 | 4.1 | 50 |
| | 10 | 8 | 9.0 | - | - | - |
| Weedy rice | 0 | 92 | 5.1 | 31.2 | 3.7 | 45 |
| | 1 | 92 | 5.2 | 31.5 | 3.6 | 56 |
| | 3 | 88 | 5.3 | 32.3 | 3.4 | 37 |
| | 5 | 88 | 6.5 | 27.5 | 3.1 | 26 |
| | 7 | 52 | 7.7 | 26 | 2.0 | 21 |
| | 10 | 0 | - | - | - | - |
| Rice | 0 | 96 | 5.3 | 25.3 | 3.8 | 40 |
| | 1 | 96 | 5.3 | 28.3 | 3.6 | 47 |
| | 3 | 72 | 6.5 | 28.8 | 3.1 | 36 |
| | 5 | 72 | 6.9 | 22.2 | 2.2 | 25 |
| | 7 | 12 | 9.0 | 15.0 | 2.0 | 21 |
| | 10 | 0 | - | - | - | - |

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# INFLUENCE OF A MIXED WEED SPECIES STAND ON COMMON BEANS IN SRI LANKA

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*Summary*: The above ground response of two common bean cultivars to weed interference from a stand of mixed weed species was studied in dry and wet cropping seasons ("Yala" and "Maha") in the mid-country of Sri Lanka during 1995 and 1996. The treatments consisted of either allowing weeds to infest the crop for increasing durations after emergence or maintaining plots weed-free for increasing periods after emergence. Top crop, a bush type (Bush bean) and Kentucky wonder green, a vine type (Pole bean) were the bean cultivars used. Season-long weed interference caused a significant decrease in fresh pod yield. However, weeds could remain up to 34 and 14 days after emergence (DAE) in pole beans and weeds that emerge with the crop start significant competition at 9 and 4 DAE in bush beans in wet and dry season respectively. The results also revealed that pole beans can tolerate weeds more than the bush bean cultivar. However, the most sensitive period of weed control for the wet season is shorter than for the dry season in both cultivars. Length of the weed-free period required to prevent more than 5% yield loss ranged from 34-36 and 14-54 DAE for pole beans in wet and dry seasons, respectively. If the 5% yield loss level is accepted for bush beans, the effective weed-free period is between 9-42 DAE and 4 DAE-end of the crop in the two seasons, respectively. Weeding before or after this period did not increased yields significantly. Unweeded plots had a loss of more than 60% compared to season long weed-free condition. The competition by weeds influenced number of pods per plant rather than other yield components in both cultivars.

*Keywords*: weed interference, *Phaseolus vulgaris*.

## INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is the most widely consumed vegetable in Sri Lanka, which belongs to Leguminosae. Common beans are grown on about 8,000 ha throughout the Island (16) and is a vital component in the Sri Lankan family diet. Cultivation of common beans is very popular in mid-county and hill-county areas where the soil is more liable to erosion.

Weeds play an important role in reducing erosion by heavy rains during fallow periods and even when there is a crop. The awareness of environmental sustainability has also increased efforts to reduce herbicide use in agriculture. Therefore, control during period in which weeds cause significant crop losses is a very important consideration in the challenge to feed more people, while avoiding soil erosion, chemical pollution and destruction of wild plants and animals.

The effective weed-free period or "critical period of weed interference" has been determined for a variety of crops (9, 13, 19, 21, 25). This critical period is defined as an interval in the life cycle of the crop when it must be kept weed-free to prevent yield loss (26, 27). Researchers (13) also describe critical period of weed control as the time interval involving two components. The first component is the maximum length of time that weeds emerging with the crop can remain before they reduce crop yield. The second component is the length of time a crop must be kept weed-free after planting so that weeds emerging later do not reduce yield. The two components can be integrated to identify a simple effective weed-free period recognized as the duration over which neither component provides an acceptably low yield loss. Weed control must be effective within the period of overlap between the two components (25).

There have been critical period studies conducted on *Phaseolus vulgaris* for dry seed production (8, 25). However similar studies have not been carried out in the tropics although studies on critical period on grain legumes and other crops have been reported (11, 15). The effective weed-free period depend on the crop species (5, 20, 24), crop density (17), weed species (10, 22), weed density (2) and environmental conditions (17). Therefore, the objective of this study was to determine most effective weed-free period in common bean for the two principal crop growing seasons in Sri Lanka.

## MATERIALS AND METHODS

Experiments were conducted on different fields in 1995-96 wet season ("Maha") and 1996 dry season ("Yala") at the Dodangolla University Research Farm, University of Peradeniya, Sri Lanka. The soil was a Ultisol with 1.44% OM, 6.08 pH and 1.16% OM, 6.78 pH in the two fields used in wet and dry seasons, respectively.

Commonly grown bean cultivars Top Crop, a bush type (Bush bean) and Kentucky Wonder Green, a climbing type (Pole bean) were the cultivars used. Weed-free seedbeds (3x3 m for bush bean and 3x4 m for pole bean) were prepared by ploughing and harrowing. Plots were seeded at the recommended spacing (3) (10x50 cm for bush bean and 45x60 cm for pole bean) in the two seasons beginning in September (wet) and June (dry) respectively. A basal mixture of 145, 130 and 90 kg/ha of N, P and K were applied at seeding and 125 kg/ha of urea was applied as top dressing at flowering. Insects and diseases were controlled with recommended chemicals (3).

Treatments representing increased duration of weed interference allowed weeds to grow with beans from emergence until the following WAE : 2, 3, 4, 5, 6, and 1, 2, 3, 4, 5, 6 for bush bean and 3, 6, 9 and 2, 3, 4, 5, 6 in pole bean in 1995 and 1996, respectively. Weeds were removed by hand and plots maintained weed-free for the remainder of the season. Treatments representing increasing duration of weed control were maintained free of weeds until the beans reached following WAE : 2, 3, 4, 5, 6, and 1, 2, 3, 4, 5, 6 for bush bean and 3, 6, 9 and 2, 3, 4, 5, 6 in pole bean in 1995 and 1996 respectively. Thereafter weeds were allowed to grow for the reminder of the season. In addition each trial had season long weed-infested and weed-free treatments. Fresh bean yield per plant and yield as percentage of weed-free control were calculated. All yield data were presented as percent of the weed-free check to simplify comparisons between seasons. Gompertz (7) and Logistic (18) equations were used to quantify the yield data under increasing length of weed-free and weed-infested periods, respectively.

## RESULTS AND DISCUSSION

*Climate*: Total rainfall received during 3 months of the crop (October, November and December) in 1995-96 "Maha" and 1996 "Yala" (June, July and August) growing seasons were 587.5 and 258.8 mm, respectively. These figures were similar to the 10 year average values of 567.6 and 258.9 mm of the two seasons.

*Yield*: Yields from all treatments were greater in wet season than in dry season regardless of cultivar. Although season-long weed interference reduced fresh pod yield, the presence of weeds up to 34 and 14 DAE in pole bean and 9 and 4 DAE in bush bean did not reduce yield by over 5% in wet "Maha" and dry "Yala" seasons, respectively.

*Critical period (CP) of weed control*: The parameter estimates for the best fitted Gompertz and Logistic equations for both cultivars and seasons are presented in Table 1. In both cultivars there were relatively short critical periods for wet "Maha" and long CPs for dry seasons.

Table 1. Parameter estimates for Gompertz[a] and Logistic[b] equations and critical periods

| Cultivar | Season | Gompertz equation | | | Logistic equation | | | | CP |
|---|---|---|---|---|---|---|---|---|---|
| | | A | B | K | D | K | F | x | |
| Bush bean | 1995-96"Maha | 102.02 | 1.995 | 0.079 | 0.88 | 0.175 | 1.532 | 20 | 9-42 |
| | 1996"Yala" | 100.01 | 1.10 | 0.05 | 0.793 | 0.109 | 1.729 | 20 | 4-end |
| Pole bean | 1995-96"Maha | 100.02 | 0.698 | 0.063 | 0.095 | 0.359 | 2.263 | 31 | 34-36 |
| | 1996"Yala" | 100.00 | 1.30 | 0.06 | 1.268 | 0.232 | 1.471 | 24 | 14-54 |

[a]Y=Aexp(-Bexp(-KT)); Y=yield (% of season-long weed-free bean); A=asymptote (% of season-long weed-free bean); B,K=constants; T=time from bean emergence (days)
[b]Y=((1/D*exp(K*(T-x))+F))+((F-1)/F))*100%; Y=yield (% of season-long weed-free bean); T=time from bean emergence (days); x=point of inflection (days); D,F,K=constants
CP=Critical weed-free period to prevent more than 5% yield loss (DAE)

Based upon an arbitrary 5% level of yield loss, the CP of weed control occurred approximately between 34-36 DAE and 9-42 DAE for pole and bush beans respectively in the1995-96 wet season (Fig.1 a & b). The CPs of weed control in dry season 1996 were 14-54 DAE and 4 DAE-end of the crop growth for pole and bush beans (Fig.1 c & d). The longer CPs identified for dry season in 1996 reflected a greater yield loss due to durations of weed-interference than for the wet seasons (1995-96). The bush bean cultivar was more sensitive to weed-interference in both seasons. These results differ from reports of CP ranges in other environments. For example, researchers (12) in Nicaragua reported a CP for beans of 21-30 days after planting. Another study (25) also reported very short CPs in Canada. These results are based on bean seed production rather than fresh pods.

*Yield components*: There was a positive correlation between pods/pant and pod yield/plant with correlation coefficients (r) of 0.97 and 0.55 for pole bean in wet and dry seasons respectively. Other yield components had low correlations between fresh pod yield in pole bean. In bush bean, pod length (r=0.49, P=0.0004) and seeds/pod (r=0.57, P=0001) also had positive correlations with yield/plant in the wet season.

In the dry season, pods/plant, pod length and seed/plant contributed to pod yield (r= 0.66, 0.51 and 0.50, respectively). The number of pods/plant was the yield component most influenced by weed interference. This has also been observed elsewhere for dry bean seed production (1, 4, 23), in snap beans (14) and also in soybeans (6).

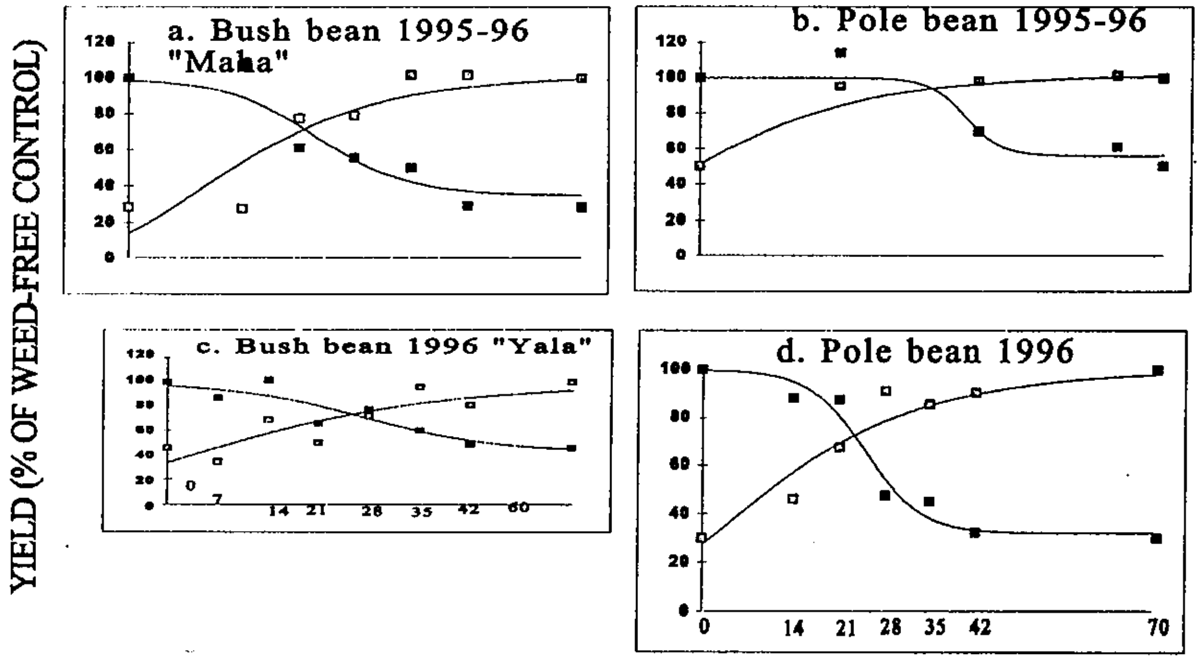


Figure 1. Crop yield as affected by increasing duration after emergence of the crop maintained as either weed-free (□) or weed-infested (■) for bush (a & c) and pole (b & d) beans in 1995-96 "Maha" and 1996 "Yala" growing season

*General discussion and conclusion*: The results, clearly showed that the critical period of weed removal was extremely variable across growing seasons. This may be attributed to a number of factors including characteristics of cultivars. Short bush type cultivars are more sensitive to weed interference than indeterminate pole bean cultivars. Hence, before developing recommendations, critical weed-free periods should be studied for different cultivars under different climatic conditions.

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# A STUDY OF THE SOIL SEED BANK OF PARTHENIUM WEED IN CENTRAL QUEENSLAND

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*Summary*: The seed bank of parthenium weed, a serious pasture weed, was studied at two sites in central Queensland (Australia). The germinable seed bank was determined from soil samples collected on four separate occasions, each six months apart, between February 1995 and October 1996. The results confirmed that parthenium weed was very prominent in the seed bank and always accounted for between 47% and 87% of the total number of seed which germinated. A record of emergence was kept which revealed that parthenium weed seedlings emerged more quickly than any other species, hence gaining a competitive edge.

*Keywords*: parthenium weed; germinable seed bank; seedling emergence

## INTRODUCTION

Parthenium weed (*Parthenium hysterophorus* L.; Asteraceae) is a major pasture weed of Queensland, Australia (15) which has the ability to dramatically reduce the productivity of pastures (6), affect the well-being of livestock (13), cause serious allergic health problems in humans (12), and become a significant weed of crops (5). This annual weed causes problems in many countries located in the tropical or sub-tropical regions of the world, and it is especially damaging in India. In heavily infested areas the carrying capacity of pastures can be reduced to near zero, and entire properties have reported a 40% reduction (11). It is estimated that this weed costs the beef cattle industry of central Queensland about US$ 13.5 million per annum (2). The worst infestations of this weed occur in areas that have undergone clearing or have been overgrazed. In central Queensland in areas where there is continued heavy grazing, parthenium weed dominates native pastures on many soil types (11). Parthenium weed is also a harmful environmental weed which causes total habitat change in native grasslands and along rivers and floodplains (2,15).

The soil seed bank of a plant community contributes significantly to the ability of that community to regenerate, and to the distribution pattern of the vegetation, while the seed production of the vegetation influences the composition and abundance of the seed bank (14). Hence, seed banks are important to the ecology of communities and to the recruitment of species, especially those that rely mostly or totally on non-vegetative means of reproduction. In rangelands, grazing pressure usually leads to a decline in the density of perennial grasses and an increase in the population of annuals and woody species (14,16). Similar effects are also noticed in the seed banks of areas that are heavily grazed (7,14).

Inadequate research has been conducted on the seed bank of parthenium weed. Neither has research been conducted on the seed banks of other species, in areas infested by the weed, and how they are affected by the weed. The only mention of the seed bank of parthenium weed in the literature is a brief statement by Joshi (8) that the seed population of this weed is about 200 000/m$^2$ in abandoned fields in India. Some research is currently being conducted in central Queensland on the seed bank of parthenium weed, however it is yet to be completed (J. Chamberlain, pers. comm., 1996). Apart from this, the size of the seed bank of parthenium weed can only be guessed from reports on the amount of seed produced by this weed (4,10) and the density of germinating seedlings in the field (9). The purpose of this present study is to determine the size and dynamics of the seed bank of parthenium weed in grazed pastures in central Queensland, and to compare these findings to the seed banks of other species over a 18-month period.

## MATERIALS AND METHODS

*Study area*: Two sites were chosen in central Queensland, the first site was located on 'Niagara', a property 50 km north of Clermont, while the second site was located near Moolayember Creek, 90 km south of Rolleston. The site near Clermont was situated in a paddock which had been used as pasture for many years and had never been cultivated. The vegetation at this site was a grassland community, with a few scattered trees, which was supported by a black, cracking clay soil. The ground cover at this site was quite low due to several years of drought, and the predominant species in the vegetation were buffel grass (*Cenchrus ciliaris* L.), wiregrass (*Aristida* sp.) and parthenium weed. The Moolayember Creek site was situated on a creek flat and possessed a sandy loam soil, it was also used for pasture. The vegetation here was open woodland and the proximity of the creek meant that there were quite a number of trees present. This site received a greater annual rainfall than the first site and hence the vegetation was more luxurious. The predominant species at this site were annual broadleaves such as parthenium weed, mexican poppy (*Argemone ochroleuca* Sweet) and cobbler's pegs (*Bidens pilosa* L.), and grasses such as summergrass (*Digitaria ciliaris* (Retz.) Koeler) and green couch (*Cynodon dactylon* (L.) Pers.).

*Data collection*: Collections of soil samples, from both sites, were made in February and October 1995, and March and October 1996. At the Clermont site 30 quadrats (each 0.5 m$^2$) were located on a grid pattern (5×6) which covered an area of 40×50 m. Five soil cores 5 cm in diameter and 3.5 cm deep were removed from each quadrat (at regular positions) using a brass ring soil corer and pooled to make a single sample. A similar collection process was conducted at Moolayember Creek, except only 20 quadrats were located on a grid (2×10) which covered an area of 5×45 m. Within a week of collection, the samples were spread thinly over a sterile soil substrate in shallow trays (15×30 cm). These trays were watered to field capacity and observed regularly, daily for the first 20 days, for newly emerging seedlings. Emerging seedlings were marked and recorded as either 'parthenium weed' or 'another species'. Once the seedlings were large enough for recognition, they were removed, and individuals grown for identification.

*Statistical analysis*: To detect differences in seed banks between sampling dates, at both sites, non-parametric tests were utilised as soil seed banks are notoriously heterogeneous. These tests were conducted on the density of seed found in each quadrat. The test chosen was a Kruskal-Wallis One Way ANOVA and differences between treatments were detected using Student-Newman-Keuls method. These tests were run after the data had undergone a $Log_{10}$ (x + 1) transformation to adjust for differences in variance.

## RESULTS AND DISCUSSION

*The seed bank at Clermont*: The germinable soil seed bank at Clermont was relatively small (3283-5095 seeds/m$^2$) and not very diverse, with only 27 species being recognised (Table I). This was not surprising considering the sparse vegetation at the site and the unfavourable condition of the paddock. In general, the seed bank was dominated by parthenium weed and grasses (82-88% of total), while a few annual weed species were also reasonably common. Legumes and non-graminaceous perennials were quite rare. Parthenium weed was the most prevalent species, accounting for 47-73% of the germinable seed bank during the period of study. The seed bank of parthenium weed varied significantly over time and increased at both the second and third sampling times, before falling again in the final batch of samples. A similar pattern was also observed in the overall seed bank, and this was probably a direct result of the changes in parthenium weed seed numbers. Temporal variation in the seed bank may be caused by the pattern of rainfall at a site and the timing of subsequent germination events, and also by the timing of input into the seed bank via the seed rain (3). Seed banks may also be significantly affected by loss of viability over time and by predation. The seed bank of parthenium weed was relatively low initially, and this was probably due to a recent period of drought. Significant rainfall events over the next 12 months lead to stands of the weed being produced, and the seed rain from these stands may have caused the increase that was detected over the next two sampling periods. The final soil collection was made subsequent to a significant germination event, as was evident when the samples were collected, which may explain the lower numbers of seed present in October 1996.

Table I. Temporal variation in the germinable soil seed bank of a pasture near Clermont, Australia.

| Species | Seeds (m$^2$)[1] | | | |
|---|---|---|---|---|
| | March 1995 | October 1995 | March 1996 | October 1996 |
| *Amaranthus spinosus* | 26 a | 291 b | 78 a | 85 a |
| *Parthenium hysterophorus* | 1544 a | 2028 b | 3701 d | 2386 c |
| *Tribulus terrestris* | 0 a | 54 a | 0 a | 20 a |
| *Verbena bonariensis* | 52 a | 7 a | 26 a | 3 a |
| *Zaleya galericulata* | 0 a | 0 a | 20 a | 36 a |
| | | | | |
| EUPHORBIACEAE | 48 a | 42 a | 157 b | 7 a |
| POACEAE[2] | 1138 a | 830 a | 780 a | 1181 b |
| Others[3] | 96 | 45 | 88 | 21 |
| Unknown | 379 | 127 | 245 | 326 |
| | | | | |
| TOTAL | 3283 a | 3424 b | 5095 d | 4065 c |

[1] numbers followed by the same letter in each row are not significantly different.

[2] including *Aristida* sp., *Cenchrus ciliaris*, *Cynodon dactylon*, *Digitaria ciliaris*, *Enneapogon* sp., *Eriochloa crebra*, *Panicum effusum* and *Sporobolus elongatus*.

[3] including *Apium leptophyllum*, *Boerhavia* sp., *Convolvulus erubescens*, *Datura* sp., *Neptunia gracilis*, *Oxalis corniculata*, *Physalis minima*, *Sida cordifolia*, *Wahlenbergia tumidifructa* and *Xanthium spinosum*.

Several species of grasses were present in the seed bank and there was not sufficient time available for individual identification of each seedling. However, the most common species present were buffel grass, wiregrass, bottlewashers (*Enneapogon* sp.) and summergrass. The abundance of the grass seed bank was relatively stable over time (780-1181 seeds/m$^2$ ), the only significant change being an increase between the March 1996 and October 1996 samples. The relatively high grass seed density in March 1995 was due to large numbers of seed being present in a couple of samples, therefore the non-parametric method of analysis detected no difference between these samples and those collected in October 1995 and March 1996. In the other species, some temporal variation was detected in the seed banks of spiny amaranth (*Amaranthus spinosus* L.) and the Euphorbiaceae, however no distinct patterns were evident.

*The seed bank at Moolayember Creek*: The germinable seed bank at Moolayember Creek was more abundant (20605-44640 seeds/m$^2$) and diverse (at least 46 species) than the seed bank at the first site (Table II). This is probably due to the greater rainfall at this site and its proximity to a water source. Once again parthenium weed was the most common species present in the seed bank and represented an even greater proportion (65-87%) of the seed bank here than at Clermont. The grasses were common (641-2345 seeds/m$^2$), but represented a lower percentage of the seed bank here than they did at the first site. A number of other species were also quite common, especially mexican poppy and fleabane (*Conyza bonariensis* (L.) Cronq.).

Table II. Temporal variation in the germinable soil seed bank of a pasture near Moolayember Creek, Australia.

| Species | Seeds (m$^2$)[1] | | | |
|---|---|---|---|---|
| | March 1995 | October 1995 | March 1996 | October 1996 |
| *Argemone ochroleuca* | 4388 c | 60 a | 1287 b | 10 a |
| *Bidens pilosa* | 0 a | 248 b | 362 b | 117 b |
| *Chenopodium polygonoides* | 122 a | 71 a | 117 a | 5 a |
| *Conyza bonariensis* | 685 c | 127 b | 862 d | 24 a |
| *Crassula colorata* | 647 a | 21 a | 279 a | 0 a |
| *Gamochaeta subfalcata* | 188 b | 11 a | 480 c | 5 a |
| *Juncus* sp. | 11 a | 0 a | 1136 b | 0 a |
| *Lepidium* sp. | 536 b | 230 b | 357 b | 0 a |
| *Oxalis corniculata* | 613 c | 39 b | 558 c | 0 a |
| *Parthenium hysterophorus* | 22597 ab | 31662 b | 33904 b | 17579 a |
| *Solanum mauritianum* | 497 a | 258 a | 113 a | 108 a |
| *Verbena bonariensis* | 332 a | 35 a | 122 a | 10 a |
| CYPERACEAE[2] | 1293 b | 425 a | 367 a | 162 a |
| POACEAE[3] | 641 a | 1551 a | 2345 b | 1111 a |
| Others[4] | 218 | 278 | 642 | 93 |
| Unknown | 1918 | 1282 | 1709 | 1381 |
| TOTAL | 34686 b | 36298 b | 44640 b | 20605 a |

[1] numbers followed by the same letter in each row are not significantly different.

[2] including *Cyperus gracilis* and *Cyperus polystachyos*.

[3] including *Aristida* sp., *Brachiaria piligera*, *Cenchrus ciliaris*, *Chloris truncata*, *Cynodon dactylon*, *Digitaria ciliaris*, *Elusine indica*, *Eragrostis brownii*, *Eragrostis elongata*, *Eragrostis pilosa*, *Panicum effusum* and *Sporobolus elongatus*.

[4] including *Alternanthera pungens*, *Amaranthus spinosus*, *Apium leptophyllum*, *Casuarina cunninghamiana*, *Centipeda minima*, *Chenopodium cristatum*, *Chenopodium melanocarpum*, *Dysphania glomulifera*, *Eucalyptus* sp., *Euphorbia* sp., *Portulaca oleracea*, *Rumex* sp., *Salsola kali*, *Sida cordifolia*, *Verbena tenuisecta*, *Wahlenbergia gracilis*, *Wahlenbergia tumidifructa* and *Zaleya galericulata*.

Temporal variation was quite prominent in the seed banks of species at this site. In fact temporal variation was detected in the seed banks of eight species and two families (ie. the Poaceae and Cyperaceae). Four species (fleabane, cudweed (*Gamochaeta subfalcata* (Cabrera) Cabrera), creeping oxalis (*Oxalis corniculata* L.) and mexican poppy) expressed quite obvious seasonal changes in their seed banks. All of these species had significantly larger numbers of seed germinate from the autumn (March) samples than from the spring (October) samples. This seasonal variability in the number of stored seed indicates the transient nature of these species in the seed bank (3).

The size of the seed bank of parthenium weed, at this site, was reasonably constant until October 1996, when a significant decrease was detected. As at Clermont, a significant germination event may have partially depleted the seed bank at this site, however the drop in seed numbers was too large to be caused by this alone. Increasing activity of the seed-feeding weevil *Smicronyx lutulentus* Dietz., a biological control agent released to control parthenium weed, was detected at this site and may be impacting on the weed's seed bank by reducing the seed rain. Once again a similar pattern of temporal variation, to that expressed by parthenium weed, was demonstrated by the overall seed bank. As a number of other species were less common in the seed bank in spring, parthenium weed represented a greater proportion of the seed bank at this time of year (85-87%) than it did in autumn (65-76%). The rainfall of this area is summer dominated and the wet season usually begins in October or November. It has been observed that if decent rainfall occurs at this time, proliferous germination of parthenium weed ensues and a dense stand of this weed is produced. These seed bank studies demonstrate that competition from other species is likely to be lowest if germination occurs at this time of year, and partially explains why parthenium weed is so aggressive at this site.

*Seedling emergence*: The record of the emergence of seedlings from the soil samples collected near Clermont in March 1995 revealed a peak in parthenium weed emergence 3 days after wetting of the samples, in comparison the emergence of all other species peaked 9 days after wetting (Figure I). Parthenium weed accounted for 91% of germinants 3 days after wetting, and 86% of germinants 4 days after wetting, yet it accounted for only 47% of the final number of seedlings which emerged.

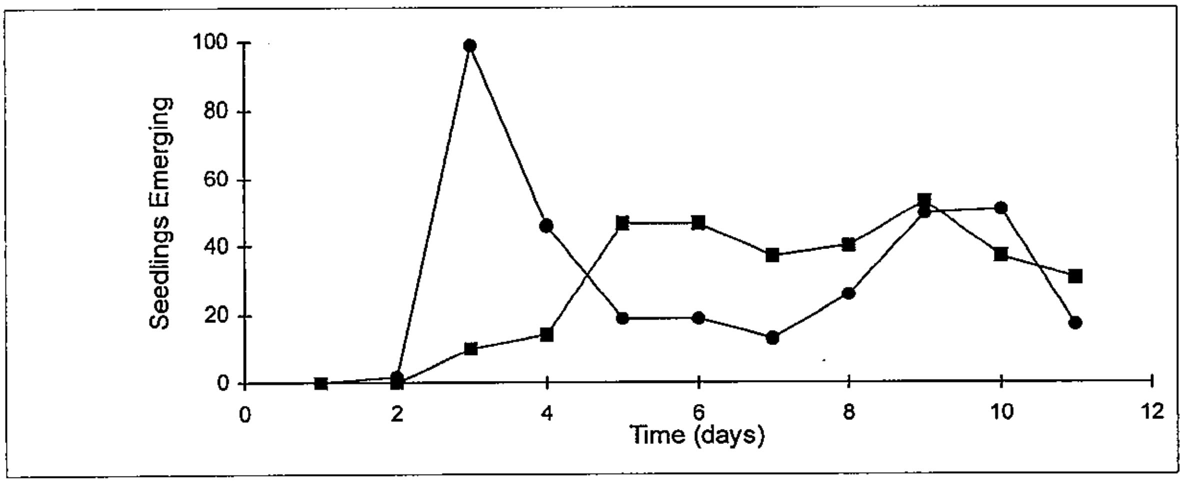


Figure 1. The rate of emergence of seedlings (● *Parthenium hysterophorus*; ■ all other species) from soil samples collected near Clermont in March 1995.

A rapid germination rate is known to be important to seedling establishment and can provide a competitive advantage (1). At sites where there is a dense infestation of parthenium weed, its seedlings have been observed to germinate quickly and form a dense carpet which inhibits the germination of other species. This data demonstrates that the seed of parthenium weed generally emerge more quickly than those of all other species at this site, thereby giving them a competitive advantage. A similar pattern was observed in the emergence of seedlings from the Moolayember Creek samples collected in October 1995 (data not shown), however the effect was even greater as parthenium weed accounted for a larger proportion of the seed bank at this site.

## ACKNOWLEDGEMENTS

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# CHARACTERISTICS OF GERMINATION AND SUSCEPTIBILITY TO HERBICIDES IN MARSH DAYFLOWER (*MURDANNIA KEISAK* (HASSK.) HAND.-MAZZ.)

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*Summary*: Studies were carried out to analyse the conditions for germination and the susceptibility of marsh dayflower treated by 9 herbicides. The mature seeds stored under dry conditions were distinct in their innate dormancy. The dormant seeds of marsh dayflower mostly germinated at alternating temperatures of 30/20°C, both under light and dark conditions when stored in water for 20 days at 5°C or soaked in concentrated sulfuric acid for one minute. Marsh dayflower was easily controlled by chloroacetamides and carbamothioates, but not by sulfonylureas. These results indicated that marsh dayflower may become a harmful weed in no-tillage or direct-seeding rice cultivation in Japan.

*Keywords*: mash dayflower, dormancy, herbicides

## INTRODUCTION

Marsh dayflower (*Murdannia keisak* (Hassk.) Hand.-Mazz.) is indigenous to Japan (2), Korea (3) and the subtropical and temperate zones of China (4). It grows on damp ground and paddy ricefields. In Japan, exhibited itself as a harmful weed in rice fields in the eighteen fifties (1). In recent times, it has increased in rice fields with direct seeding and no-tillage. We conducted this experiment to clarify the conditions for germination and the susceptibility of marsh dayflower.to herbicides.

## MATERIALS AND METHODS

Seeds were harvested at plant senescence from an indigenous population at the Experimental farm, Ibaraki University in October, 1994 and 1995. Seeds were stored outdoors in a box that was exposed to natural temperatures.

*Dormancy*: Germination test was carried out to clarify the seasonal change in seed dormancy. The seeds were collected in 1994 and stored under dry condition and in water at 5°C from 26, December. Germination test was carried out from January to May 1995. We also measured the germination rate of seeds that were stored 10, 20, 30 and 40 days in water at 5°C in March, 1995, and compared with the seeds stored outdoors. Secondly, germination test was carried out to identify the dormancy breaking mechanism. The seeds were soaked in concentrated sulfuric acid for one minute or in giberellic acid for test period. In germination tests, fifty seeds were placed in closed 9.5 cm petri-dishes on one layer of Whatman No.1 filter paper moistened with 6 ml of distilled water. Three replicates were used in each test. Tests were conducted in light and dark (12 h interval) germinators that were controlled at alternating temperature of 30/20°C (12 h interval).

*Germination*: Seeds were subjected to germination tests after dormancy breaking treatment. Days required for germination were measured in dark at 10 and 22°C. In a pot study, about 1000 seeds of marsh dayflower were seeded in 500 cm wagner pots on December 26, 1994 and the pots were placed in two conditions, namely submerged and non-submerged. Germinated seeds were counted and removed weekly until May 1995.

*Sensitivity to herbicides*: Herbicides were applied at 2-3 leaf stage, 5 cm plant height stage and 28 cm plant height stage of marsh dayflower with the recommended and one-half use rates. Table 1 shows the herbicides used in this experiment

Table 1. List of herbicides and the content of formulation*

| Herbicides | (% of content) | Herbicides | (% of content) |
|---|---|---|---|
| Bensulfuron-methyl | 0.17 | Cyhalofop-butyl | 1.8 |
| Pyrazosulfuron-ethyl | 0.07 | Molinate | 8.0 |
| Imazosulfuron | 0.3 | Bentazone | 1.0 |
| Mefenacet | 4.0 | Bentazone+MCP | 10+1.5 |
| Pretilachlor | 2.0 | | |

*granule formulated

## RESULTS AND DISCUSSION

*Dormancy*: The mature seeds harvested in October were distinct in their innate dormancy. To clarify the seasonal change of seed dormancy, we used the seeds stored under several different conditions. In winter experiment, seeds stored in dry condition at 5°C maintained dormancy until 15 May, but eighty-eight percent of seeds germinated on February 15 by storing in water at 5°C. Twenty-nine percent of seeds stored outdoor broke dormancy on May 15. In the case of seeds soaked in concentrated sulfuric acid for one minute, fifty percent of the seeds broke dormancy on January 15, but treatment with GA at 0.1 to 100 ppm did not break dormancy. In spring experiment, ninety-two percent of seeds germinated after storing in water at 5°C for more than 20 days.

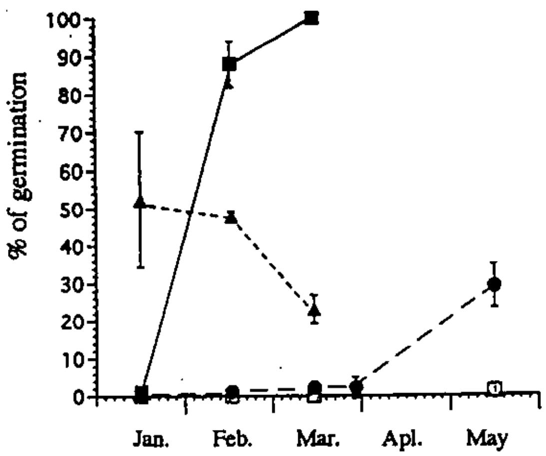


Fig. 1. Seasonal change in germination under several storage conditions.

Note: □ stored at 5°C, ■ in water at 5°C, ● in dry outdoor, ▲ soaked in sulfuric acid for one minute

Table 2. The effect of Gibellic acid (GA) in breaking dormancy of marsh dayflower

| chemicals | % germination 1994 | % germination 1995 |
|---|---|---|
| Control | 1.0±1.0 | 1.2±1.6 |
| GA 0.1 ppm | - | 1.3±2.3 |
| GA 1.0 ppm | - | 2.0±3.5 |
| GA 10 ppm | 0 | - |
| GA 100 ppm | 0 | - |
| $H_2SO_4$ | 47.9±1.3 | 65.3±6.0 |
| $H_2SO_4$ + GA 0.1 ppm | - | 62.9±7.9 |
| $H_2SO_4$ + GA 1.0 ppm | - | 65.6±7.0 |
| $H_2SO_4$ + GA10 ppm | 40.2±6.7 | - |
| $H_2SO_4$ + GA 100 ppm | 25.0±1.0 | - |

- : not tested

*Germination*: It takes about 6 days for 50% of the seeds to germinate in dark at 10°C. As temperature was raised, the time taken for germination was reduced. It took 1.5 days in dark at 22°C for 50% of the seeds to germinate. Marsh dayflower emerged in the latter period of March in outdoor pot condition. The date of emergence of marsh dayflower seeded in submerged condition was earlier than that seeded in non-submerged soil condition. However, the total number of plants that emerged in non-submerged condition was larger than the plants that emerged under submerged soil conditions.

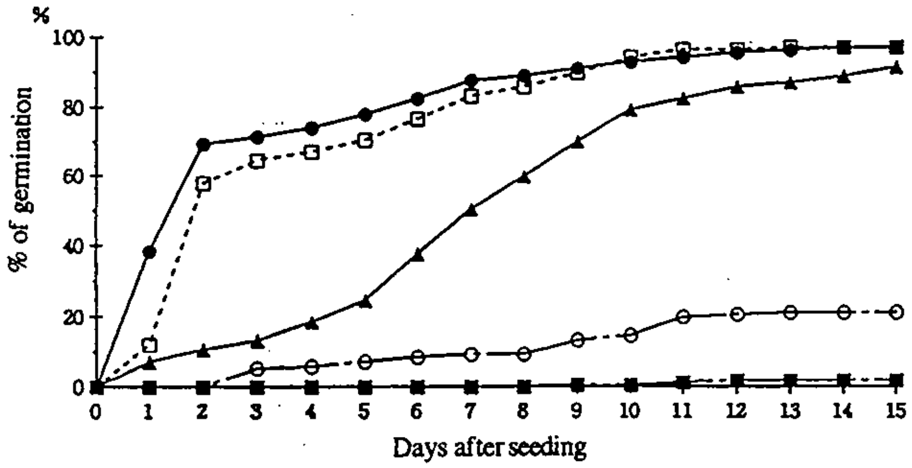


Fig.2. Cumulative germination of marsh dayflower in different storage duration in water at 5°C.
Duration of storage: ● 40, □ 30, ▲ 20, ○ outdoor

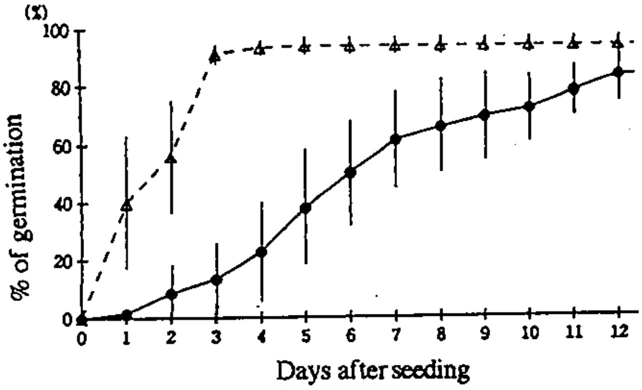


Fig.3. Cumulative germination of marsh dayflower seeds breaking dormancy in two temperature conditions.

Note: ● dark at 10°C, △ dark at 22°C
Germination test was started on April 14.

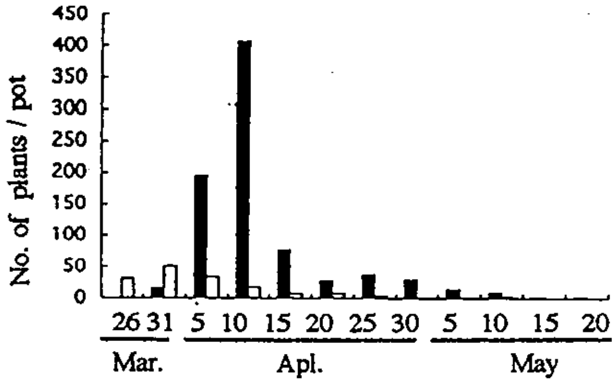


Fig. 4. Seasonal change of emerged plants under different soil-water conditions.

Note: □ submerged, ■ non-submerged

*Sensitivity to herbicides*: Mefenacet, pretilachlor and molinate exhibited excellent control of marsh day flower at the young seedling stage, but sulfonylureas and cyhalofop-butyl did not control effectively. At intermediate stage (28 cm plant height) of Marsh dayflower, only combination of bentazon and MCP gave excellent control. Pretilachlor, molinate and bentazon did not control marsh dayflower completely, but inhibited their growth.

The results are summarised as follows. The emergence of marsh dayflower outdoors began at 8°C (at mean air temperature) (5, 6). The seeds in upland soil emerged in March to May and their percentage emergence was higher than that of seeds in submerged soil. Seeds buried in submerged soil quickly lost dormancy and entered into secondary dormancy. Marsh dayflower was easily controlled by chloroacetamides (mefenacet, pretilachlor) and carbamothioates (molinate) at the 2~3 leaf stage and cut seedlings of 5 cm length. However, marsh dayflower is likely to emerge in paddy fields before transplanting or seeding of rice plant in Japan. As the combination of bentazon and MCP only inhibited the growth of marsh dayflower at the stage when the plant height had reached 28 cm, marsh dayflower may become a harmful weed in no-tillage or direct-seeding rice cultivation.

Table 3. The effect of herbicides on marsh dayflower at young growth stage.

| herbicides | dose (g/ha) | 2-3 leaves f.w. (g/pot) | 2-3 leaves % | 5 cm height f.w. (g/pot) | 5 cm height % |
|---|---|---|---|---|---|
| bensulfuronmethyl | 25.5 | 4.3 | 14 | 44.9a | 112 |
| | 51.0 | 4.5 | 14 | 40.0a | 100 |
| pyrazosulfuronethyl | 10.5 | 11.3 | 36 | 38.1a | 95 |
| | 21.0 | 5.9 | 19 | 35.4a | 88 |
| imazosulfuron | 45 | 6.1 | 19 | 39.0a | 97 |
| | 90 | 6.7 | 21 | 26.7a | 66 |
| mefenacet | 600 | 0.8 | 3 | 4.1 | 10 |
| | 1200 | 0.4 | 1 | 2.7 | 7 |
| pretilachlor | 300 | 0.4 | 1 | 2.8 | 7 |
| | 600 | 0.5 | 2 | 2.8 | 7 |
| cyhalofopbutyl | 90 | 22.6 | 71 | 27.1a | 67 |
| | 180 | 20.6 | 65 | 10.6 | 26 |
| molinate | 1200 | 1.1 | 3 | 8.5 | 21 |
| | 2400 | 1.1 | 3 | 2.6 | 6 |
| control | 0 | 31.7 | 100 | 40.2a | 100 |
| f (p<0.05) | | 5.0* | | 9.6* | |

Table 4. The effects of herbicides on marsh dayflower.at intermediate stage (28 cm height).

| herbicides | dose (g/ha) | f.w. (g/pot) | % |
|---|---|---|---|
| pretilachlor | 300 | 87.0 | 41 |
| | 600 | 74.1 | 35 |
| molinate | 1200 | 80.1 | 38 |
| | 2400 | 66.4 | 31 |
| benzatone | 1650 | 96.9 | 45 |
| | 3300 | 98.2 | 46 |
| benzatone MCP | 1500+225 | 52.8 | 25 |
| | 3000+450 | 32.3 | 15 |
| control | 0 | 213.0 | 100 |
| f (p<0.05) | | 18.2* | |

f.w.: fresh weight at 28 days after herbicides treatment.
a: no difference between means.

## ACKNOWLEDGEMENT

We wish to express our deepest thanks to agricultural chemical companies for supplying the herbicides tested.

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# VARIATION IN REPRODUCTIVE TRAITS OF *POA CRASSINERVIS* HONDA AND *P. ANNUA* L.

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*Summary: Poa crassinervis* Honda is a winter annual weed in drained paddy fields, upland fields, roadsides and gardens of western Japan. It is often dominant in these fields and grows together with *P. annua* L. Many reports concerned with life history and phenological traits of *P. annua* have been made, but no studies have beeen attempted on *P. crassinervis*. In this study, patterns of reproductive schedules of the two species were investigated. Samples were taken from 106 sites for *P. crassinervis* and 174 sites for *P. annua*. Pre-reproductive period and age-specific reproduction measured as the number of inflorescence produced per two weeks were recorded. Pre-reproductive period of *P. crassinervis* was consistantly longer than that of *P. annua*. The mode of adaptation of *P. crassinervis* to the habitats in western Japan will be discussed.

*Keywords: Poa annua* biology, *P. crassinervis* biology, variation life history

## INTRODUCTION

*Poa crassinervis* Honda, "Tsukushi-suzumenokatabira" in Japanese, is a Japanese endemic weed species (5, 6). It is found only in the western part of Japan and observed in abundance from winter to spring in Kyushu and Shikoku Islands. *Poa annua*, a closely related species known as a cosmopolitan weed, occurs throughout the northern and southern temperate regions of the world (8). The two species are sometimes found together in drained paddy fields, upland fields, roadsides and gardens in the western part of Japan. They resemble each other morphologically, but are distinguished by the shape of the upper glume and lemmas. *P. crassinervis* has narrowly elliptic glume and lemmas, its panicle branches are thicker and obliquely straight-ascending (1, 5, 6).

Weeds which grow in the various agricultural or ruderal sites such as paddy fields, vegetable fields, turf, roadsides and open spaces differentiate their life history traits for adaption to each environment. Population differentiation in response to divergent selection pressures has been recorded in many species. In *P. annua*, population differentiation in adjacent habitats such as paddy fields, golf courses and open habitats has been reported (3, 4, 7), but no studies have been attempted on the life history traits of *P. crassinervis*.

Evidence of intra-specific variations in life history traits includes characters such as fecundity, the length of the pre-reproductive period, viability and other phenological traits (2). Phenological traits of plants often involve the prediction of optimum strategies that maximize fitness through the best combination of life history traits in an environment. Intra-specific variation can be used to understand the evolution of life histories and interacting traits shaped by natural selection. Most studies of life histories compare related species.

In this study, we investigated the variation in life history among populations of *P. crassinervis and P. annua*. This paper addresses the difference in the adaptive strategy between cosmopolitan and locally distributed weed species.

## MATERIALS AND METHODS

Mature seeds of *P. crassinervis* were taken from 106 sites in western Japan, mainly Kyushu and Shikoku Islands. *Poa annua* seeds were collected from 174 sites throughout Japan. Seeds from 10-30 plants of the representative populations were sampled at collection sites. Collected seeds were dried at room temperature and stored at -20°C until the start of the experiment. For simultaneous germination in autumn, the seeds of both species packed in 0.5 mm mesh clothes were buried at a depth of 5-10 cm in the upland field of Faculty of Agriculture, Shinshu University on May 30, 1996. They were dug up on September 16, 1996 and ten seeds of each population of both species were sown in 2.8 $cm^2$ paper pots on September 19, 1996.

When the first three leaves had appeared, seven seedlings of each population in both species were individually transplanted to plastic pots (12 cm in diameter and 10 cm deep) filled with soil (N:0.35, $P_2O_5$:1.5, $K_2O$:0.35 g/kg) on

October 26, 1996. Seedlings were grown in a greenhouse under natural day length and temperature was maintained above 5°C during the study. Life history traits were recorded as follows : pre-reproductive period taken as the time from emergence to heading, maturing time taken as the days to set first seed. Age-specific reproduction measured as number of inflorescence produced per month was also recorded.

## RESULTS AND DISCUSSION

Most *P. crassinervis* populations headed between 55-65 days after emergence. A few populations of *P. crassinervis,* which were collected from southern Japan: Amami Island and Ibusuki, Kagoshima Pref., contained individuals with extreme delays (>90 days). Only one population collected from Fukuoka Pref. headed within 50 days. In *P. annua,* many populations headed between 50-65 days, and heading time of each population fluctuated widely between 35-110 days. It was clear that *P. annua* had early-heading populations that headed within 50 days. *Poa annua* contained about 35 populations of the early-heading type, which were collected from Okinawa, Kanagawa, Miyazaki, Tokusima, Chiba and Miyagi Pref. *Poa annua* also contained individuals with extreme delays (>90 days). These were collected from Okinawa, Kagoshima, Yamaguchi, Nagano, Kanagawa and Hokkaido pref. In Okinawa, Kanagawa, Chiba and Kagoshima, there were also extreme early- and delay-types of *P. annua.* It seems that there was no relationship between geographical distribution and heading time of *P. annua.*

Most populations in both species matured 90-110 days after emergence. In *P. annua,* the early heading type matured within 80 days. In both species, correlations between heading and maturing time taken as the days to set first seed had highly significant linear regressions. The results showed significant inter-specific differences between *P. annua* and *P. crassinervis. Poa annua* tended to head early in contrast with *P. crassinervis.* On the other hand, *P. crassinervis* tended to mature early in contrast with *P. annua.*

The differences could be observed in age-specific reproduction measured as the number of inflorescence produced per month. The number of inflorescence produced in both species gradually increased in February, but the number of inflorescence of *P. annua* was significantly much more than that of *P. crassinervis* after March. Final number of inflorescence in *P. annua* was also much more than that of *P. crassinervis.* In *P. annua,* reproductive characters varied more among populations than among species. Continual inflorescence production was found in *P. annua* which headed at 50-60 days. High productive potential for seed production was found in *P. annua.*

The results show that *P. annua* populations had the early heading types with high potential for seed production, in contrast with that of *P. crassinervis.* The characters of the early heading and the continual production of inflorescence may be essential for cosmopolitan weeds. Variation among populations in productive traits was found in both species, but the range of variation among population was consistently much greater in *P. annua.* There were few variations for reproductive traits in *P. crassinervis.*

In the western part of Japan, *P. crassinervis* and *P. annua* usually grow together in the various habitats. *Poa crassinervis* was relatively earlier maturing and the duration in many populations in both species was almost similar. If the habitat is kept free of disturbance for about 90-110 days, it is likely that both weeds would grow together in the habitat.

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# VARIATION IN PAPPUS NUMBER AND ACHENE SIZE OF *MIKANIA MICRANTHA* H.B.K IN THAILAND

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*Summary*: Morphological characteristic in achene is an important key to distinguish *Mikania micrantha* H.B.K from close relatives distributed in Southeast Asian countries. Pappus number and achene size were measured on samples of *M. micrantha* collected from five locations in Thailand. Average length ranged from 1.6 to 1.9 mm for achene and 2.6 to 2.9 mm for pappus. Significant difference was recognized in the pappus number with the range from 28.6 for the sample from Chiang Mai to 36.9 for that from Surat Thani. Although 32 to 38 pappus numbers has been described for *M. micrantha* by Holm *et al* (2), achene size has also to be considered for the correct identification of *M. micrantha* in Thailand.

*Keywords*: achene, *Mikania micrantha,* pappus, Thailand

## INTRODUCTION

*Mikania* (Composite) is a genus which includes several noxious weeds in the tropics, such as *M. micrantha* H.B.K., *M. scndens* Willd., *M. Cordifolia* Willd. and *M. cordata* B.L. Robinson (2). *M. Cordata* is a native species of tropical Asia and India, while the others have been introduced from South America. In Thailand, *M. micrantha* was newly recorded in the weed flora (3, 4), although only *M. cordata* has been recognized as a noxious weed of the rubber plantations in southern districts (1, 5). The information on the correct identification is desired to clarify weed problems of *M. micrantha* in the country. The morphology of achene and pappus was investigated as significant characters for distinction using specimens of *Mikania* collected in Thailand.

## MATERIALS AND METHODS

Samples of *M. micrantha* were collected during the weed survey carried out in northern and southern Thailand in December 1993 and 1994. They were made into three sets of specimens and kept in the Bangkok Herbarium and the University of Kyoto (KYO) prior to this study. An additional sample was obtained from Hat Yai, Songkhla Province in February 1997. Size of achene and pappus number were examined for 80 florets of 20 capitula on the stereo microscopic photograph. Achene with pappus was pressed with a cover glass in order to get uniform focus on the photograph.

## RESULTS AND DICUSSION

| Location | Latitude (°N) | Habitat |
|---|---|---|
| 1. Chiang Mai | 18.8 | Waste place |
| 2. Chumphon-1 | 10.4 | Levee of paddy field |
| 3. Chumphon-2 | 10.4 | Rubber plantation in Chumphon Horticultural Research Center |
| 4. Surat Thani | 8.9 | Oil palm plantation |
| 5. Hat Yai | 7.0 | Rubber plantation in Hat Yai Rubber Research Center |

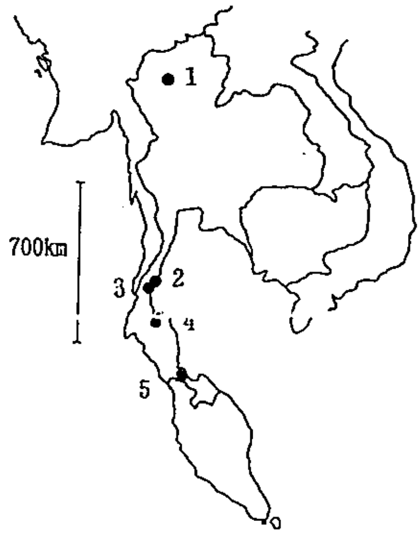


Fig. 1 Location and habitat of *Mikania micrantha* collected in Thailand.

Fig. 2 *M. micrantha* in rubber plantation in Chumphon Hortikultur Research Center.

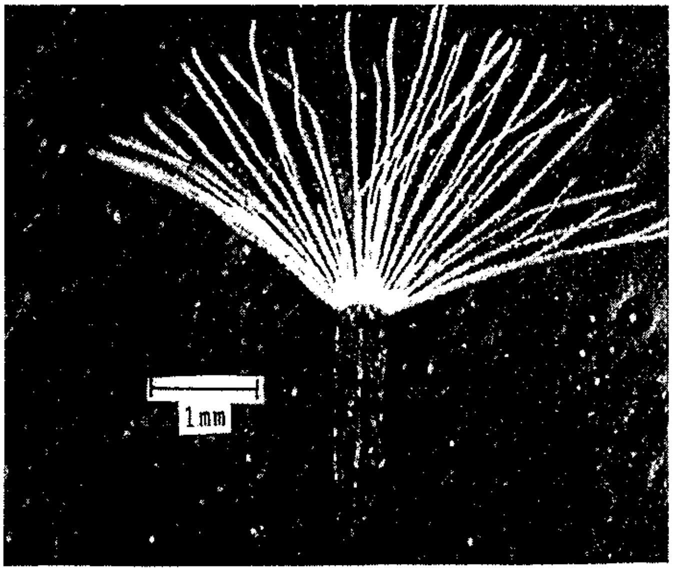


Fig. 3 Achene and pappus of *M. micrantha*.

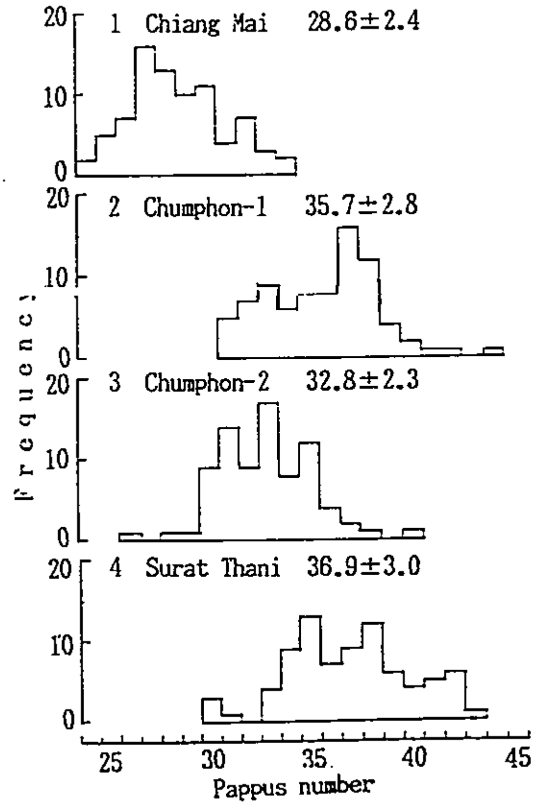


Table 1. Length of achene and pappus of *Mikania micrantha* from five locations in Thailand.

| Location | Number of samples examined | Length (mm)* | |
|---|---|---|---|
| | | Achene | Pappus |
| 1 Chiang Mai | 28 | 1.7±0.1 | 2.7±0.1 |
| 2 Chumphon-1 | 17 | 1.9±0.1 | 2.7±0.2 |
| 3 Chumphon-2 | 24 | 1.8±0.1 | 2.6±0.2 |
| 4 Surat Thani | 36 | 1.6±0.1 | 2.7±0.1 |
| 5 Hat Yai | 17 | 1.8±0.1 | 2.9±0.3 |

*:Average±S.D.

*Distribution and habitat*: Mikania micrantha was distributed throughout the country from northern to southern districts (Fig. 1). It occurred in waste places of urban areas, levee of paddy fields, rubber and oil palm plantations (Fig. 1 and 2). The species flower in December and February of each year.

*Length of achene and pappus*: Small or no differences were recognized in the length of matured achene and pappus among samples from the five locations. Average length ranged from 1.6 to 1.9 mm for achene and from 2.5 to 2.7 mm for pappus (Fig. 3 and Table 1).

*Pappus number on achene*: The pappus color was white in all samples. There were significant differences in the average number among four samples, with the range from 28.6 for the sample from Chiang Mai to 38.9 for the samples from Surat Thani (Fig. 4). Pappus number of sample from Hat Yai was 38.

Although the samples from Chiang Mai had pappus numbers greater than 32-38 reported by Holm *et al* (2), it was identified as *M. micrantha* by its white pappus which never turned reddish or purple. The results suggest that *M. micrantha* is distributed more widely than *M. cordata* in Thailand; *Mikania cordata* was not collected during this weed survey. Since the pappus number varied among samples from different locations and individuals, while differences in achene and pappus were inconspicuous, all characters should be examined for correct identification of *M. micrantha* in Thailand.

## ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to Dr. H. Nakamura, former leader of NWSRI project of JICA and Dr. P. Kittipong, Director of Botany and Weed Science Division of DOA Thailand for giving the opportunity for the weed survey. Heartfelt thanks are extended to Dr. J. Harada, NIAES Japan and Dr. S. Zungsontiporn, NWSRI Thailand for their valuable suggestions on this study.

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# EFFECT OF CYANAMIDE ON SEED DORMANCY AND RESPIRATORY ENZYME ACTIVITY OF *ECHINOCHLOA ORYZICOLA* VASING.

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*Summary*: Cyanamide ($CN_2$), an active ingredient of calcium cyanamide fertilizer, was studied for reconfirmation on its dormancy-breaking activity against seeds of *Echinochloa* weeds and on the effects on respiratory enzyme activity. When applied to a paddy field in fall, the fertilizer at dosages from 300 to 700 kg/ha broke dormancy of *E. oryzicola* seeds and induced seedling emergence. The number of seedlings accounted for *ca.* 60% of the total seed number present in soil upto 2 cm in depth. In laboratory experiment, it was apparent that cyanamide had remarkable efficacy in breaking dormancy of the weed seeds at 10 mM. Seeds treated at 100 mM lost viability. Cyanamide at the optimum concentration did not inhibit oxygen uptake by seeds and showed little effect on activity of cytochrome *c* oxidase, alcohol dehydrogenase, glucose-6-phosphate dehydrogenase and peroxidase, whereas that of catalase was markedly inhibited.

*Keywords:* cyanamide, *Echinochloa* spp., seed dormancy

## INTRODUCTION

Seed dormancy is of great importance for many weeds to survive under unfavorable environmental conditions and build up the seed bank in soil. A number of studies have been conducted to elucidate mechanisms of seed dormancy and many chemicals were found to have dormancy-breaking activity in laboratory experiments (6, 7). However, most of them are not applicable to farmer's fields. For instance, many respiratory inhibitors such as KCN and $NaN_3$ are remarkably effective in breaking of weed seed dormancy, but they are extreme poisons.

In 1965, a Japanese farmer found a large number of *Echinochloa* weeds seedlings at his rice field after harvesting the crop in early fall. He applied calcium cyanamide, a nitrogen fertilizer ($CaCN_2$), after rice to prepare the field for planting radish (Ishihara, pers. comm.). Ishihara *et al.* (3) and others reported dormancy-breaking activity of cyanamide against *Echinochloa* weed seeds. However, this farmer's finding was not evaluated since many herbicides, which are effective in rice growing season, have been rapidly developed and extended.

Herbicides are indispensable chemical agents to control weeds in crop fields, but it is also true that we have a fear of environmental problems with chemical agents. The objective of this study was to reconfirm the dormancy-breaking activity of calcium cyanamide against dormant seeds of *Echinochloa* weeds in both field and laboratory experiments. We think that the fertilizer is not a quick-activating agent to control weeds, but has potentialities not only to reduce size of the seed bank when applied after rice, but to induce uniform germination of the weed when applied before rice.

## MATERIALS AND METHODS

*Field experiment*: The field used for experiment was a paddy field (loamy sand, pH 6.0 ($H_2O$), OM at 8.3%) where *Echinochloa oryzicola* Vasing. (hereafter, oryzicola) was grown with 20x20 cm spacing. Above-ground parts of the plants were harvested on 1 October, 1996. Calcium cyanamide fertilizer (Powder formulation, 50% calcium cyanamide) was broadcasted on 7 October at 0, 300, 500 and 700 kg/ha to the 1x3 m plots arranged in a completely randomized design with three replications. A little standing water was present on the soil surface at application. Total density of oryzicola seeds up to 2 cm in depth of soil was nearly 4,500 seeds/$m^2$. The number of emerging seedlings was counted periodically from 25 October to 20 November (18 to 44 days after application), using a 30x30 cm quadrat, at three locations per plot.

One hundred seeds present at a layer from soil surface to 2 cm in depth were recovered from each of three locations per plot in early December. Seed viability was tested by pressing them with a forceps. The seeds easily squeezed were identified as those which lost viability. The remaining seeds were subjected to a laboratory germination test at 30°C in the light for a week. Ungerminating seeds were further subjected to the TTC test described elsewhere (5).

*Laboratory experiments*: Experiments were conducted with an identical strain of oryzicola with that used in the above field experiment. The fertilizer is composed of calcium cyanamide and carbon, and we found it difficult to prepare an aqueous solution with designated cyanamide concentrations. Therefore, we used hydrogen cyanamide ($H_2CN_2$) in laboratory experiments. Dormancy-breaking activity of cyanamide was tested by imbibing 100 dormant oryzicola seeds with the aqueous solutions at various concentrations in the light at 30°C for 10 days. Oxygen uptake and respiratory enzyme activity in extract of the treated seeds were also determined according to Yamasue *et al.* (8).

## RESULTS AND DISCUSSION

*Field experiment*: No oryzicola seedlings were observed in the check plot with no cyanamide application (Fig. 1). However, in plots treated with the fertilizer, more than one hundred seedlings per $m^2$ were observed at 18 days after application (25 October). The number of seedlings linearly increased afterwards in treated plots and reached about 2,500 seedlings/$m^2$ at 44 days after application (20 November). There were little difference in emerging seedling number among the dosages. All of the seedlings died at end December when soil maximal temperature decreased to 10°C.

When seeds were recovered from soil surface layer and tested for their state of dormancy, 98% of seeds in the check plot did not germinate under the optimum conditions in the light at 30°C, but showed positive response to the TTC test. They were considered to remain dormant (Fig. 2). On the contrary, in plots treated at 500 kg/ha, seeds with their dormancy broken accounted for 59%, and remaining 13 and 28% were dormant and dead seeds, respectively.

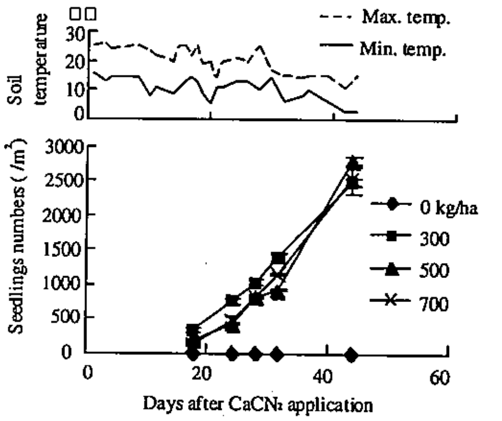



Figure 1. Emergence of *Echinochloa* weed seedlings by CaCN2 application. CaCN2 was treated on 7 October, 1996. Values are means + s.e.

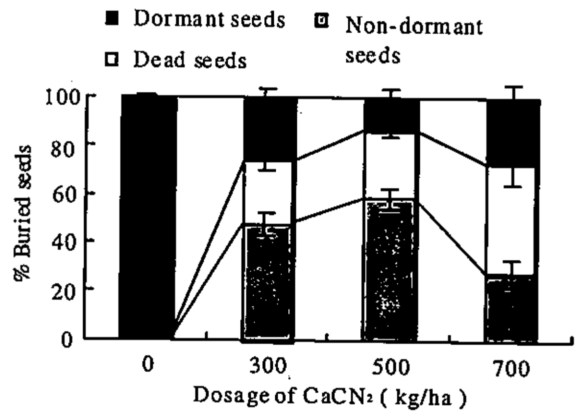



Figure 2. Dormant state of soil-buried seeds of *Echinochloa oryzicola* after about 50 days from CaCN2 application. Values are means ± s.e.

*Laboratory experiments*: When oryzicola seeds were treated at concentrations from 0.001 to 100 mM for 10 days, hydrogen cyanamide showed optimum concentration at 10 mM in breaking dormancy of oryzicola seeds and induced 60% germination, while no germination was observed at concentrations less than 10 mM (Fig. 3). The seeds treated at 100 mM did not respond to TTC test and were defined as killed by the chemical. Oxygen uptake of the seeds treated at the optimum concentration was traced from initial imbibition to 72 hrs, but no effect was observed (Fig. 4). Crude enzyme extracts of seeds treated at 10 mM also did not show any inhibition or stimulation of activities of several respiratory enzymes such as cytochrome *c* oxidase, glucose-6-phosphate dehydrogenase and peroxidase. However, catalase activity was remarkably inhibited until 24 hrs (Fig. 5).

The cyanamide fertilizer was reconfirmed to be effective in breaking seed dormancy of oryzicola both in field and laboratory experiments (Fig. 1 and Fig. 3). It was also effective against seed dormancy of other species such as *E. crus-galli* var. *crusgalli* and *E. crus-galli* var. *praticola* (data not shown). However, the cyanamide efficacy in fields may vary depending on soil temperature and moisture conditions. The weed seeds require enough temperature and moisture to absorb the fertilizer and germinate in soil. The reasons why we were able to observe a large number of oryzicola seedlings in the field experiment were that the mean daily temperature was far exceeding 15°C (Fig. 1) and soil was under water-saturated condition when the fertilizer was applied. More trials are required to clarify the conditions for it to be utilized in fields.

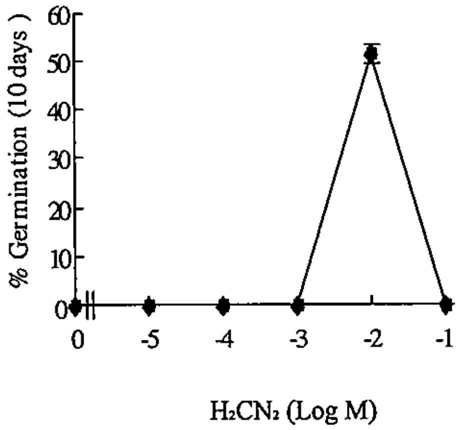



Figure 3. Percent germination of *Echinochloa oryzicola* with various concentrations of H2CN2. Values are means ± s.e.

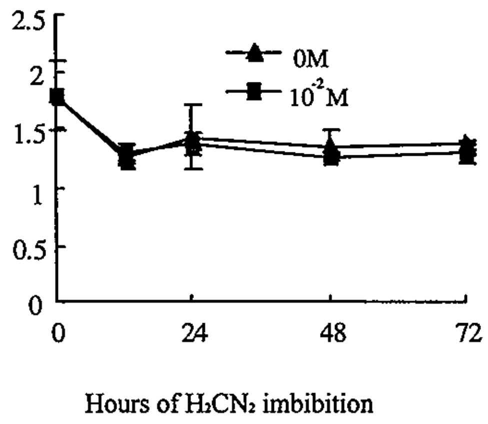
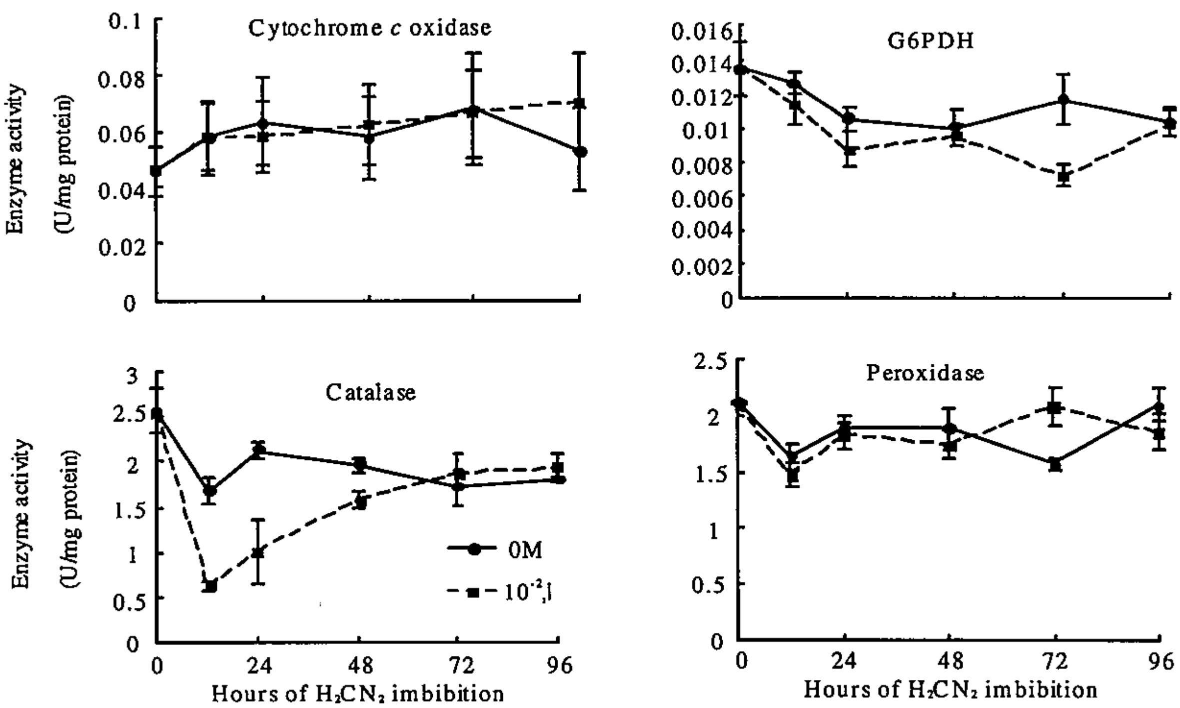



Figure 4. Oxygen uptake of *Echinochloa oryzicola*. treated with H2CN2. Values are means ± s.e.

Figure 5. Changes in respiratory enzyme activities in seeds of *Echinochloa oryzicola* treated with $H_2CN_2$. Values are means ± s.e.




On effects of cyanamide on respiratory enzyme activity, Inoue *et al.* (2) reported that the chemical inhibited catalase activity. We also observed the catalase inhibition in extract of the treated oryzicola seeds (Fig. 5). Catalase is also inhibited in oryzicola seeds treated with KCN (8). However, these two dormancy-breaking agents differed in their effects on oxygen uptake and cytochrome *c* oxidase. KCN severely inhibited the oxidase activity as well as oxygen uptake, but cyanamide did not (Fig. 3 and 5). And a chemist suggests no conversion from $CN_2$ to CN in soil. In mammalian tissues, cyanamide conjugates with cysteine and forms *N, S*-diguaninocysteines (4). *N, S*-diguaninocysteine may release thiourea and *N*-guaninocysteine. Thiourea is a well known chemical with dormancy-breaking activity against a wide variety of weed seeds. Hendricks and Taylorson (1) reported that dormancy-breaking activity of thiourea correlated with inhibition of catalase activity in seed extracts of *Amaranthus albus* and *Lactuca sativa*, and proposed a scheme; thiourea shifts the internal $H_2O_2$ breakdown to peroxidase by inhibiting catalase and increase operation of pentose phosphate pathway through stimulation of NADPH oxidase activity, which leads dormant seeds to germinate. But applicability of this scheme is not valid yet for cyanamide against oryzicola weed seeds.

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# REPRODUCTIVE AND SEED GERMINATION CHARACTERISTICS OF WOODY BORRERIA (*DIODIA OCIMIFOLIA*) IN A PLANTATION ECOSYSTEM

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*Summary:* Woody borreria is well adapted to shade. Plants survived, grew and reproduced at 1 to 100% radiation. At 9 to 100% radiation, it flowered and produced capsules within 90 days after sowing. Buried seeds of woody borreria retained its viability for more than one year. It retained its viability better when buried in soils under mature oil palm than under a legume cover crop (LCC). Deeper burial depths also favoured seed persistence. Light is essential for seed germination, but reduced radiation at 75 μ moles/cm$^2$/s did not affect germination. Woody borreria seeds were able to emerge from depths of 2 cm. The viable options to manage the weed are the use of LCC at replanting, chemical control in the rows or circles, and encouragement of natural ground covers such as ferns in the inter-rows.

*Keywords*: woody borreria, *Diodia ocimifolia*, seed viability.

## INTRODUCTION

*Diodia ocimifolia* (Willd, ex R. & S.) Bremek) is the new name for woody borreria, which was previously known as *Hedyotis verticillata* (L) Lamk. (5). It is fast becoming an important weed in plantations in Malaysia. In 1986, woody borreria was mostly concentrated in the southern state of Johore in Peninsular Malaysia (10). By 1993, it had spread to every state in Malaysia except Perlis, Kelantan and Penang Island in the north (1, 4). Estate managers ranked woody borreria as the most difficult weed to control in both immature and mature plantations (1). The intractability of woody borreria had prompted some studies on its control, seed production and nutrient lock up (2, 3, 4, 6, 7, 10).

This paper reports on the reproductive and germination characteristics of woody borreria in relation to its ecology. Such characteristics can provide ideas to further improve its management in plantations.

## MATERIALS AND METHODS

*Phenology and reproductive characteristics under open and shaded conditions*: The experiment was carried out in Novartis R&D Station Rembau on a sandy clay loam (Rengam series). Seeds collected from Tebung Estate were sown under black polyethylene nets (TILDE net). The nets were graded as 50%, 90% and 95% shade by the manufacturer. These shade levels were equivalent to 36, 9 and 1% light transmission, respectively, based on actual measurements of radiation at 12 noon on a clear day. No net was used for the 0% shade level. The experiment consisted of four shade levels within which 12 plants were grown and sampled for measurements. The plants were measured for canopy diameter, flowering, fruit set, height and seed production.

*Viability of buried seeds under mature oil palm and legume cover crop (LCC)*: The study was conducted in Novartis R&D Station at Rembau, an oil palm small-holding adjacent to the Station and Tebung Estate. The soil in all sites was a sandy clay loam (Rengam series). The site on the Station was covered with a legume cover crop (*Pueraria phaseoloides*). The sites in the small-holding and Tebung Estate were under mature oil palm planted in 1983 and 1987, respectively; the canopy had already closed providing nearly 90-100% shade. The dominant weed was *Nephrolepis bisserata*, *Diodia ocimifolia*, *Axonopus compressus*, *Mimosa pudica*, *Urena lobata* and *Calopogonium caeruleum*.

Two hundred seeds were placed inside each nylon-mesh bag measuring 5x5 cm. The bags were placed on the soil surface, buried in the soil at 7.5 or 15 cm deep. The experimental design was a split split-plot with sites as main plots, burial depths as sub-plots and sampling times as sub-subplots. There were six replicates. The bags were exhumed and checked for seed germination and viability by the tetrazolium test at intervals of about 30 days.

*Effect of light on dormancy*: The experiment was carried out in pots filled with a sandy clay loam (Rengam series). Each pot was sown with 50 seeds on the soil surface. There were five treatments of light intensities: clear polyurethane cover which allowed 70-80 μ moles/cm$^2$/s radiation, shade net (TILDE net) of 50% grade over a clear polyurethane which allowed 50-65 μ moles/cm²/s radiation, shade net of 90% grade over a clear polyurethane which allowed 6-7 μ moles/cm²/s, dark check where the pots were wrapped with two layers of aluminium foil over a clear polyurethane, and an uncovered check which allowed 200 μ moles/cm²/s radiation. The pots were arranged in a completely randomized design with three replicates. Seed germinability was estimated by counting emerged seedlings. Germinated seeds in the dark check were counted in the dark under green light (8, 9).

*Effect of seed burial depth on emergence*: The experiment was carried out in pots filled with a sandy clay loam (Rengam series). Each pot was sown with 100 seeds at 0, 0.5, 1, 2, 4 or 8 cm depth. The layout was a completely randomised design with four replicates. Seed germinability was estimated by counting emerged seedlings.

## RESULTS AND DISCUSSION

*Phenology and reproductive characteristics under open and shaded conditions*: Woody borreria is an extremely plastic species in all shade conditions. It began to emerge at 7 days after sowing regardless of shade level (Table 1). Plants grown under 100% and 36% radiation were of similar vigour. Plants at 9 and 1% radiation still grew and produced seeds, but such light intensities clearly limited photosynthesis.

The high capacity for seed production at 9 to 100% radiation shows that any plant that escapes the initial control can easily re-populate a given area. To reduce seed set, weed control should be carried out not later than 80 days after emergence. At this growth stage, the weed is still young and would not hinder estate operations such as tapping or harvesting of fruit bunches.

Table 1. Growth stages of woody borreria expressed in time after sowing under four levels of radiation.

| | Phenology of woody borreria under varying radiation[1] compared to open sky | | | |
|---|---|---|---|---|
| | 100% [765] | 36% [279] | 9% [65] | 1% [8] |
| Time to emergence (d) | 7 | 7 | 7 | 7 |
| Time to flowering (d) | 51 | 51 | 57 | 200 |
| Time to fruiting (d) | 62 | 62 | 67 | 214 |
| Time to capsule production (d) | 79 | 79 | 85 | 225 |
| *At 226 DAS:* | | | | |
| Seed production (no) | 15,000 | 15,000 | 6,500 | 10 |
| Plant height (cm) | 88 | 78 | 44 | 10 |
| Plant diameter (cm) | 141 | 120 | 83 | 12 |

[1]Figures in [ ] are actual radiation (μ moles/cm²/s).

*Viability of buried seeds under mature oil palm and legume cover crop (LCC):* In the first 30 days of burial, seeds under oil palm showed higher germination than those under LCC in all burial depths (Table 2). At 60 days and after, there was little effect of vegetation on the persistence of seeds on the soil surface or buried 7.5 cm deep. Seeds buried 15 cm deep under oil palm appeared to be more persistent than under LCC especially after 185 days of burial. The lower number of viable seeds under LCC as compare to under oil palm was due to higher seed loss through predation or deaths after germination.

As deep burial at 15 cm favoured the persistence of woody borreria, cultivation may encourage long-term build up of a persistent seed bank although the seeds are unlikely to germinate below 4 cm deep (Fig. 2). However, LCC appears to be an excellent method of management to reduce seed survival. In replanting areas previously infested with woody borreria, the use of pure LCC is perhaps the best method to keep the weed under control.

Table 2. The effect of burial depth and surface vegetation on the persistency of woody borreria seeds.

| Duration of burial (d) | Persistency of seeds (%) | | | | | | Laboratory check |
|---|---|---|---|---|---|---|---|
| | Depth of burial under LCC (cm) | | | Depth of burial under oil palm (cm) | | | |
| | 0 | 7.5 | 15 | 0 | 7.5 | 15 | |
| 30 | 10 | 11 | 14 | 21 | 33 | 32 | 81 |
| 61 | 14 | 14 | 13 | 4 | 17 | 20 | 39 |
| 93 | 2 | 15 | 22 | 1 | 14 | 24 | 35 |
| 126 | 3 | 12 | 22 | 4 | 10 | 23 | 21 |
| 185 | 1 | 10 | 8 | 1 | 10 | 22 | 27 |
| 228 | 0.3 | 11 | 8 | 0.3 | 10 | 22 | 0 |
| 272 | 0.3 | 4 | 3 | 0.2 | 9 | 10 | 4 |
| 316 | 0 | 7 | 5 | 1 | 6 | 10 | 15 |
| 373 | 0 | 4 | 4 | 2 | 12 | 21 | 12 |

*Effect of light on dormancy*: Radiation recorded at noon on a clear cloudless day was 765 μ moles/cm²/s. Reducing radiation to as low as 75 μ moles/cm²/s did not affect germination (Figure 1). Further reduction of radiation to 6.5 μ moles/cm²/s, which was less than 1% of radiation under the open sky, only reduced germination to 42%. However, germination was totally inhibited at 0% radiation.

Woody borreria emergence may be minimized by increasing the level of shade through natural ground covers in the inter-rows. Such natural covers like *Nephrolepis bisserata* can increase shade at the ground level to nearly 100% under mature oil palm. Together with the usual rounds of chemical weed control in the rows or in the circle, the encouragement of *Nephrolepis bisserata* in the inter-rows can reduce the populations of woody borreria long-term.

*Effect of seed burial depth on emergence*: Despite its small seed size, woody borreria emerged from a sowing depth of 2 cm (Fig. 2). However, no plants emerged from 4 and 8 cm depths. It is not known whether woody borreria germinated but it did not emerge from depths of 4 and 8 cm. As it is unlikely that light reached the depth of 2 cm in this experiment, the stimuli for germination could be the interaction of light with other factor(s).

Control of seed emergence by burying seeds through cultivation is effective only if seeds are buried at or greater than 4 cm deep. However, cultivation should be practiced once only at replanting before the sowing of LCC as it encourages the build up of the seed bank (Table 2).

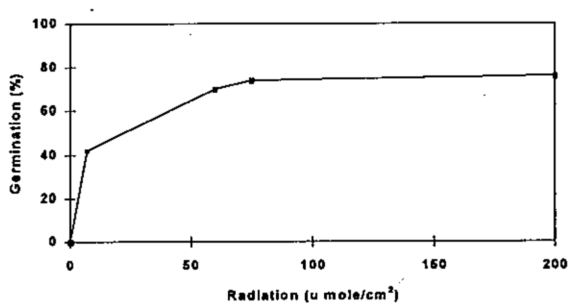


Figure 1. Effect of light on the germination of woody borreria. Germination (%) = 16.72 + 1.02 (μ moles/ cm²/s) - 0.01 (μ moles/cm²/s); $R^2$ = 0.68.

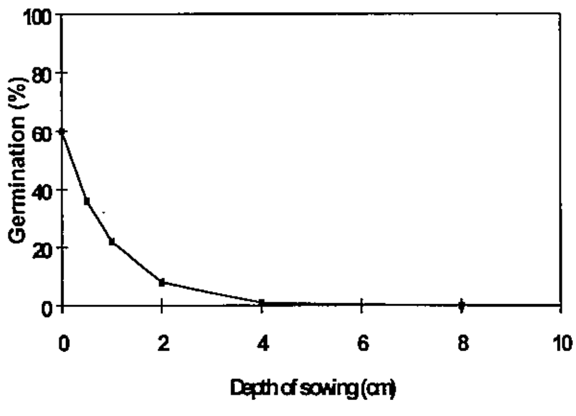


Figure 2. Germination of woody borreria at six sowing depths. Germination (%) = $60^{e\text{-depth}}$; $R^2$ = 0.82.

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# CHANGES IN PHYSICO-CHEMICAL SOIL PROPERTIES, MAJOR SOIL NUTRIENT CONTENTS, AND VEGETATION IN PADDY FIELDS DURING FALLOW PERIOD

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*Summary*: Changes in physico-chemical properties and major nutrient contents were investigated in the soil of paddy fields during fallow period. Weed vegetation change in the fallow paddy fields was also examined. As the fallow period became longer, organic matter content in the paddy soil increased gradually. Soil pH of the paddy fields did not change until three years of fallow period and there after increased slightly. Cation exchange capacity of the paddy soil, and N, K, Ca and Mg contents in the soil tended to decrease until three years of fallow period and then increased with the prolonged fallow period. As the fallow period became longer, $P_2O_5$ content in the paddy soil decreased continuously. $SiO_2$ content in the paddy soil did not change until three years of fallow period and thereafter increased. The vegetation in the fallow paddy fields were dominated by weeds of Gramineae, Cyperaceae, and Compositae. As the fallow period became longer, the weeds of the Polygomaceae and Juncaceae increased, whereas the weeds of the Leguminosae, Commelinaceae, Pontederiaceae and Onagraceae gradually disappeared.

*Keywords*: fallow paddy field, weed vegetation, dominant weeds.

## INTRODUCTION

Arable paddy fields in Korea have gradually been reduced by increased industrialization and urbanization. Particularly, paddy fields having low productivity and difficulties in mechanization have rapidly been changed to fallow fields. Increase in fallow paddy fields reduces total rice production, and causes changes in soil environment and weed vegetation in the fields. In addition, much effort and expenses would be incured when the fallow paddy fields are to be converted to arable fields (2, 5). Since fallow paddy fields are not been provided with irrigated water, fertilizers, and cultivation, physico-chemical soil properties and soil nutrient contents in the fields will change. Furthermore, weed vegetation in the fields also change (1). Weeds having higher competitive ability in the fields under the fallow condition become dominant. Weeds from other arable or non-arable lands adjacent to the paddy fields have also infested and thereby caused weed vegetation change (1, 2).

In the present study, changes in physico-chemical soil properties and major soil nutrient contents were examined in paddy fields with different fallow periods. Weed vegetation change was also monitored to characterize dominant weeds in the paddy fields and to predict the future vegetation change. This information will be useful when the conversion of fallow paddy field to arable fields is needed.

## MATERIALS AND METHODS

*Determination of physico-chemical soil properties*: Fallow paddy fields were selected from nine different areas in Naju, Hwasoon, and Seungju counties of the southeastern part of Korea. Surface soil samples (1 to 15 cm from the top) were separately collected from the paddy fields of different fallow periods (1, 3, and 5 years). Soil samples were air dried, sieved through 2-mm mesh, and their physico-chemical properties were analyzed. Organic matter (OM) contents were determined according to the method of Tyurin (6). Soil pH was measured by using a pH meter, after the soil samples were suspended with five volumes of distilled water. After subsequential extraction, distillation, and titration of the soil samples, cation exchange capacity (CEC) was determined (6).

*Analysis of major soil nutrient contents*: Dry sieved soil samples as above were also used for analyzing major nutrients. Total N content was measured by the Kjeldahl method (4). Available phosphorus ($P_2O_5$) content was determined by the method of Lancaster (6). K, Ca, and Mg contents were analyzed by using an atomic absorption spectrometer (6). Available $SiO_2$ content was colorimetrically determined according to the standard method (6). The nine areas of the fallow paddy fields examined were classified based on their physico-chemical soil properties and major soil nutrient contents by using the minimum variance clustering method (3).

*Weed vegetation change in fallow paddy fields*: Weeds grown in 1×1 m sections of the above fallow paddy fields were separately collected and identified. The weeds were counted individually and their fresh weights were measured. In addition, weed distribution rates depending on the fallow period were calculated. All experiments for each measurement were triplicated in three different paddy fields of same fallow period.

## RESULTS AND DISCUSSION

*Physico-chemical soil properties of fallow paddy fields*: Physico-chemical soil properties were compared in fallow paddy fields with different fallow periods with respect to OM, pH, and CEC. OM content in the paddy soil gradually increased, as the fallow period became longer (Table 1). This was probably due to the increased decomposition of pre-existing plant residues. Soil pH of the paddy fields did not changed until three years of fallow period and thereafter increased slightly with the prolonged fallow period (Table 1). On the other hand, CEC of the paddy soil tended to decrease until three years of fallow period and then increased with the prolonged fallow period (Table 1).

Table 1. Physico-chemical soil properties of paddy fields with different fallow periods.

| Fallow period (year) | OM (%) | PH (1:5) | CEC (me/100 g) |
|---|---|---|---|
| 1 | 2.87 ± 0.170 | 5.32 ± 0.100 | 8.19 ± 1.691 |
| 3 | 3.20 ± 0.082 | 5.33 ± 0.065 | 6.32 ± 0.523 |
| 5 | 4.03 ± 0.205 | 5.55 ± 0.110 | 8.31 ± 0.557 |

*Major soil nutrient content in fallow paddy fields*: Total N content in the soil of the fallow paddy fields decreased until three years of fallow period and then increased with the prolonged fallow period (Table 2). Similar tendency was observed in K, Ca, and Mg contents in the paddy soil. As the fallow period became longer, $P_2O_5$ content in the paddy soil continuously decreased by approximately 50% in two years (Table 2). $SiO_2$ content in the paddy soil did not change until three years of fallow period and thereafter increased by approximately 40% with the prolonged fallow period (Table 2).

Table 2. Major soil nutrient content in paddy fields with different fallow periods.

| Fallow period (year) | N (%) | $P_2O_5$ (ppm) | K | Ca | Mg | $SiO_2$ (ppm) |
|---|---|---|---|---|---|---|
| | | | (cmol/kg) | | | |
| 1 | 0.17 ± 0.017 | 63.3 ± 8.99 | 0.17 ± 0.128 | 1.88 ± 0.897 | 0. 59 ± | 38.3 ± 8.65 |
| 3 | 0.09 ± 0.008 | 38.0 ± 1.63 | 0.09 ± 0.029 | 1.05 ± 0.332 | 0.304 | 39.3 ± 2.62 |
| 5 | 0.16 ± 0.012 | 16.7 ± 9.03 | 0.17 ± 0.051 | 2.25 ± 0.694 | 0.32 ±0.136 | 50.7 ± 9.96 |
| | | | | | 1.35 ±0.390 | |

Levels of major soil nutrients examined except $P_2O_5$ were all higher in five-year-fallow paddy fields than those in one-year-fallow paddy fields. These results suggest that soil fertility in the paddy improved with the prolonged fallow period (5). The nine areas of the fallow paddy fields examined were grouped based on their physico-chemical soil properties and major soil nutrient content by using disimilarity indices. They could be classified into three distinct groups; group I for three-year-fallow, group II for one-year-fallow, and group III for five-year-fallow paddy fields (Fig. 1).

*Weed vegetation change in fallow paddy fields*: At the first year fallow period, vegetation in the paddy fields was mostly occupied by weeds of Gramineae, Cyperaceae, Leguminosae, Commelinaceae, and Pontederiaceae (Fig. 2). The weeds of the Gramineae and Cyperaceae were always dominant in the paddy fields during the fallow period. As the fallow period became longer, the weeds of the Leguminosae, Commelinaceae, Pontederiaceae, and Onagraceae gradually disappeared, whereas the weeds of the Polygomaceae, Compositae, and Juncaceae tended to increase (Fig. 2). Among them, *Leersia japonica*, *Bidens frondosa*, *Juncus effusus*, and *Aneilema keisak* were found to be the most dominant weed species (data not shown). With the prolonged fallow period, perennial weeds, upland weeds, and annual grasses had generally become dominant in the fallow paddy fields. These results might be due to the fact that no irrigation and cultivation were carried out in the fallow paddy fields. No irrigation to the fallow paddy fields caused upland weeds to flourish. No cultivation might have led to increased abundance of annual grasses which readily established near the soil surface and which have relatively shorter periods of dormancy (1, 5, 7). On the contrary, annual broadleaf weeds greatly decreased since they require deep soil disturbance to bring buried seeds to the soil surface. Since perennial weeds are not easily controlled by herbicides and cultivation, the dominant weeds found in the fallow paddy fields will cause a serious problem when the fallow paddy fields are converted to arable fields (1).

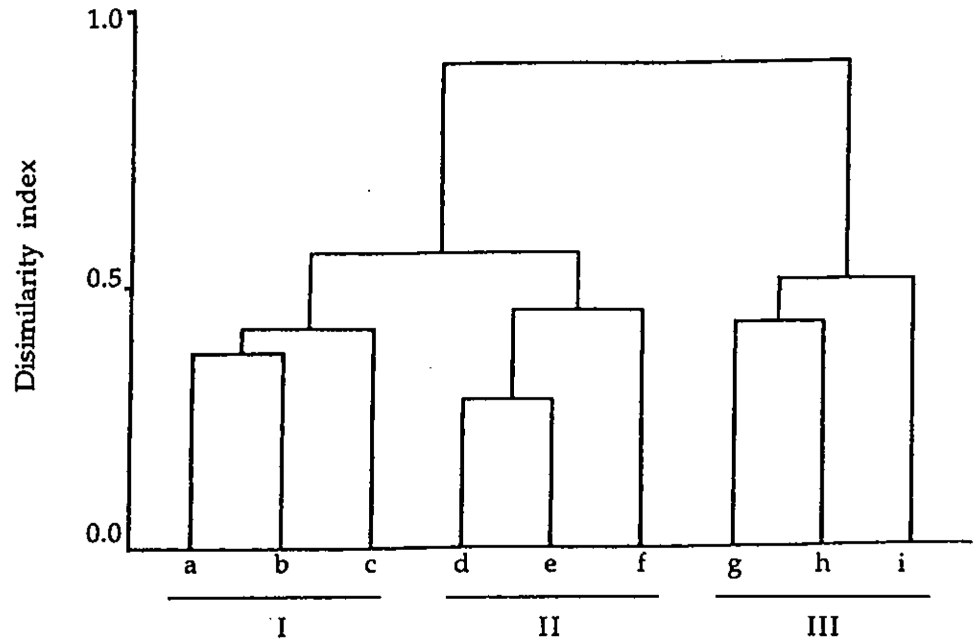


Fig. 1. Dendrogram of soil properties on nine areas (a to i) of paddy fields with different fallow periods.

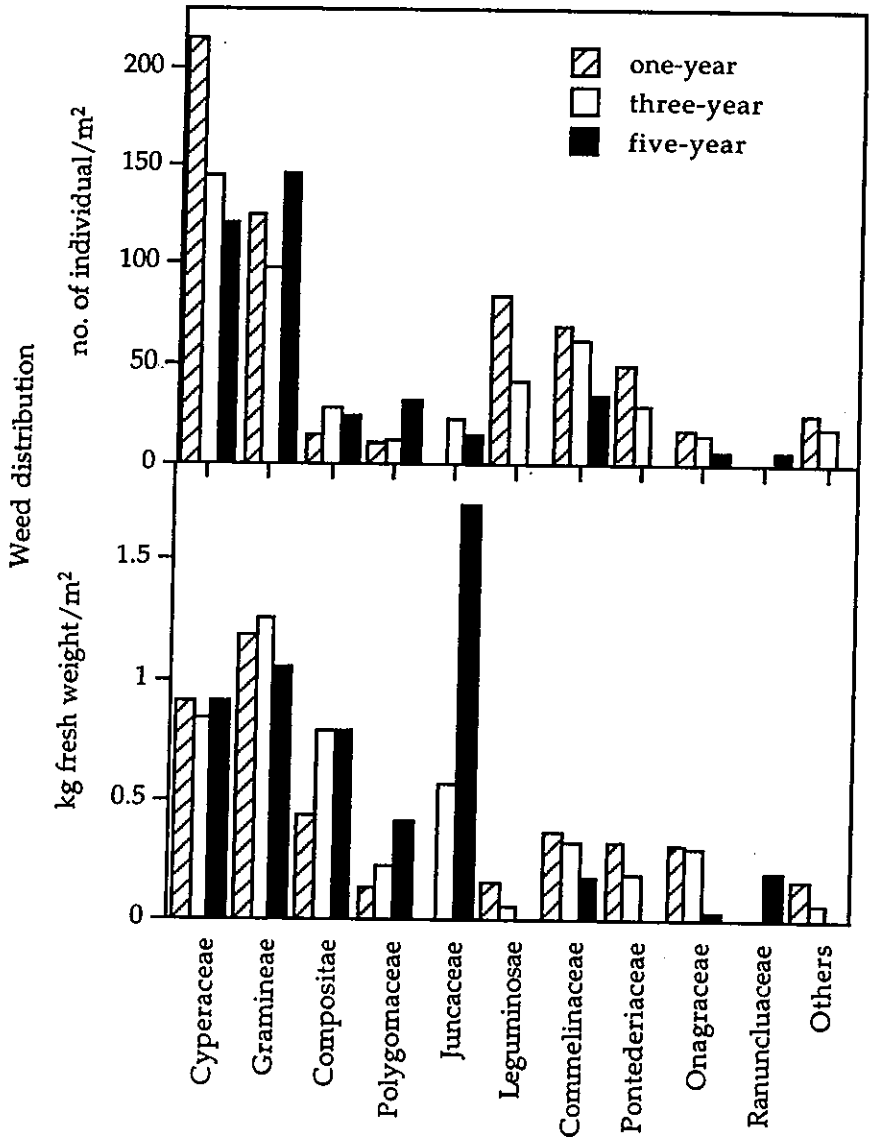


Fig. 2. Weed distribution in paddy fields with different fallow periods.

## ACKNOWLEDGEMENTS

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# EFFECT OF INTER- AND INTRA-SPECIFIC COMPETITION ON GROWTH OF FAT HEN

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*Summary:* Changes in growth characteristics of fat hen (*Chenopodium album* L.) under inter- and intra-specific competition were studied in field plots. Fat hen was grown in mixtures with four wheat varieties, Alexandria, Tonic, Canon and Baldus, and in pure stands at densities of 200, 400 and 600 plants/m$^2$. The effects of competition on fat hen were greater with inter-specific competition. The responses of the weed to different varieties were also different. Plant height was reduced by inter-specific competition but not intra-specific competition. Leaf area, shoot weight and seed yields decreased with increase in weed density but the responses were identical between 400 and 600 plant/m$^2$. All vegetative plant characters increased with time but the rate of increase was higher in intra-specific condition. Seed production was correlated with shoot weight. The highest number of seeds produced per plant was 2306 in pure stand under the density of 200 plants/m$^2$.

*Keywords*: intra-specific competition, inter-specific competition, *Chenopodium album*

## INTRODUCTION

Fat hen is an important weed in a number of crops all over the world (2, 5, 7). It may persist in agricultural fields due to the presence of large reserves of seeds in soil, its ability to escape many control measures through seed dormancy and its genetic diversity (8, 13, 14). Harrison (4) noted that a relatively low infestation of fat hen left uncontrolled for a single season is capable of producing enough seeds to maintain weed populations that could exceed economic thresholds for several years. Therefore, knowledge of its behaviour under different competition stresses will be useful for planning better weed control measures. The objective of this investigation was to observe the effects of competition from wheat varieties and from different densities of fat hen on growth characteristics related to its competitive ability.

## MATERIALS AND METHODS

The experiment was conducted in field conditions at Craibstone, Aberdeen, Scotland (57° N) during the period from 15 May to 10 October, 1996. The fat hen seeds were scarified and chilled at 2°C for 3 weeks before sowing in the field. The weed was grown in mixtures with four varieties of wheat (Alexandria, Tonic, Canon and Baldus) at a target density of 400 plants/m$^2$ and in pure stands with three target densities e.g. 200, 400 and 600 plants/m$^2$. Wheat seeds were sown in rows 17 cm apart on 15 May, 1996 with a target density of 300 plants/m$^2$. Weed seeds were broadcast on the soil surface after wheat sowing. The treatments were arranged in randomised block design. Unsown weeds were removed from time to time. Destructive samplings were done on 18 June, 3 July, 19 July and 8 August, when eight plants were collected randomly from the plots (1.3x1.3 m). After uprooting, the plants were put in polythene bags with little water so that the plants remained turgid for few hours. In the laboratory, leaf area was measured with a Delta-T Leaf area meter and plant height was recorded. The samples were then dried in an oven at 80°C for 72 h to record dry weights. Seed yield of the weed was recorded at full maturity on 5 October 1996 and harvest index (ratio of seed to total dry matter) was calculated. Data were analysed using the statistical package MINITAB and mean values were compared using LSD.

## RESULTS AND DISCUSSION

*Plant height*: Plant height of the weed was significantly reduced by inter-specific competition of wheat but intra-specific competition did not make any such reduction under the present range of weed densities (Table 1&2). Williams (16) observed that the presence of kale even in dense stands had little effect on the height of fat hen. In this study, we noted great reduction of plant height due to competition from wheat. Obviously, crop plants vary in their effects on associated weeds (6, 11). The weed was suppressed differently by different wheat varieties. For example, in comparison to pure stands, weed plant height under Alexandria was reduced more than 47%, whereas only 21-22% reduction was produced by Canon or Baldus. No significant effect of weed density on weed height was also observed by Ervio (1).

Nagashima *et al.* (9) reported that the fat hen plants in monogenic densities segregate into "upper" plants (which continue height-growth until flowering stage) and "lower" plants (whose height-growth is terminated in vegetative phase) due to intra-specific competition. The number of "upper" plants are about 100/m$^2$ irrespective of initial plant density and the number of "lower" plants increases with increase in plant density. The similar height-growth of fat hen under different densities in this experiment might be due to segregation of plants as described above. The increase in plant height over time was linear in both the conditions, but the rate of increase was much higher in case of intra-specific competition (Table 2).

Table 1. Plant height, leaf area, shoot weight and seed yield of fat hen under inter-specific competition with wheat varieties

| Plant characters | Harvest time | No wheat | Wheat varieties | | | | | l.s.d (P=0.05) |
|---|---|---|---|---|---|---|---|---|
| | | | Alexandria | Tonic | Canon | Baldus | Mean | |
| Plant height (cm) | 1st | 06.51 | 08.89 | 10.66 | 11.72 | 10.40 | 10.42 | |
| | 2nd | 30.09 | 23.88 | 30.44 | 31.38 | 31.75 | 29.36 | |
| | 3rd | 64.27 | 35.23 | 42.63 | 47.15 | 47.29 | 43.08 | |
| | 4th | 112.56 | 44.76 | 60.23 | 78.65 | 77.54 | 65.30 | |
| Mean | | 53.36 | 28.19 | 35.99 | 42.23 | 41.75 | 37.04 | 5.14 |
| Leaf area (cm$^2$ /plant) | 1st | 01.43 | 0.81 | 1.12 | 1.65 | 1.22 | 1.20 | |
| | 2nd | 11.38 | 2.50 | 3.46 | 4.25 | 4.35 | 3.64 | |
| | 3rd | 24.79 | 4.99 | 4.63 | 6.99 | 7.26 | 5.97 | |
| | 4th | 27.39 | 6.07 | 6.58 | 10.90 | 11.50 | 8.76 | |
| Mean | | 16.25 | 3.59 | 3.95 | 5.95 | 6.08 | 4.89 | 1.66 |
| Shoot weight (g /plant) | 1st | 0.07 | 0.03 | 0.04 | 0.06 | 0.05 | 0.05 | |
| | 2nd | 0.56 | 0.12 | 0.12 | 0.21 | 0.19 | 0.17 | |
| | 3rd | 2.20 | 0.33 | 0.34 | 0.60 | 0.62 | 0.47 | |
| | 4th | 4.06 | 0.48 | 0.74 | 1.72 | 1.76 | 1.18 | |
| Mean | | 1.72 | 0.24 | 0.32 | 0.65 | 0.66 | 0.47 | 0.17 |
| Seed yield (g /m$^2$) | | 243.72 | 21.95 | 50.23 | 60.08 | 73.66 | 51.48 | 26.09 |
| Seed yield (no. /plant) | | 830 | 195 | 237 | 279 | 374 | 271 | 129.39 |
| Harvest index | | 0.30 | 0.32 | 0.33 | 0.27 | 0.28 | 0.30 | 0.08 |

*Leaf area*: Weed leaf area per plant was reduced greatly by inter-specific competition. On average, there was a reduction of 70% of leaf area by the competition pressure of wheat. The effects were different under different varieties of wheat. The highest reduction was under Alexandria and the lowest under Baldus. The leaf characteristics of the four wheat varieties were different i.e. drooping leaves in Alexandria and Tonic, and erect leaves in Canon and Baldus. This seems likely to lead to different interception of photosynthetically active radiation which would affect leaf area development of fat hen. In case of intra-specific competition, although leaf area per plant decreased with increase in weed density, the difference disappeared between the densities of 400 and 600 plants/m$^2$. Similar responses of weed density on leaf area development of fat hen was observed by Williams (16) and Ervio (1). An increase of 100 wheat plants in mixtures, led to a reduction of 71% of leaf area. The mean leaf area of fat hen increased linearly over time under both inter- and intra-specific competition stresses (Table 1&2). However, the rate of increase was higher at early stages of growth.

*Shoot weight*: The effects of inter-specific and intra-specific competition on plant height and leaf area produced by the weed were reflected on its shoot weights. On average, about 74% of weed weight per plant was reduced by competition from wheat. The responses of the weed to different varieties of wheat differed. The highest suppression was from Alexandria (86% reduction) followed by Tonic (81% reduction) and the lowest suppression was given by Baldus (62% reduction). Karim (6) and Richards (12) also observed variable competition pressure of different crop species on different weeds. The shoot weight increase with time was as similar to leaf area. The reduction in shoot weight of fat hen with the increase in plant density was also significant. The highest per plant shoot weight was recorded in the lowest density. Similar decreases in weed weight with increase in weed density have beeen reported by others (1, 3, 14, 10). Although weed dry weight per plant decreased with increase in plant density, difference between the densities of 400 and 600 plants/m$^2$ was negligible. The maintenance of similar weed weight per plant between these densities suggested the existence of compensating factor due to branching (15) and/or segregation of plants into "upper" and "lower" plants (9). However, weed weight per unit area increased with increase of weed density and the highest value was noted under the highest density. Ervio (1) stated that dry weight of fat hen per unit area increased with density up to a ceiling value of 576 plants/m$^2$. Sibuga and Bandeen (15) observed both similarity and dissimilarity between the dry weights of fat hen under different densities. The increase of dry weights with time was linear but the rate of increase was higher in monoculture.

Table 2. Plant height, leaf area, shoot weight and seed yield of fat hen under different densities of the weed

| Plant characters | Harvest time | Weed density | | | Mean | l.s.d. (P=0.05) |
|---|---|---|---|---|---|---|
| | | 200 /m$^2$ | 400 /m$^2$ | 600 /m$^2$ | | |
| Plant height (cm) | 1st | 7.06 | 6.52 | 6.27 | 6.22 | |
| | 2nd | 24.38 | 30.09 | 30.66 | 28.38 | |
| | 3rd | 70.86 | 64.27 | 69.05 | 68.06 | |
| | 4th | 133.42 | 112.56 | 118.61 | 121.53 | |
| Mean | | 58.93 | 53.36 | 56.15 | 56.15 | 4.73 |
| Leaf area (cm$^2$/plant) | 1st | 1.42 | 1.24 | 1.17 | 1.28 | |
| | 2nd | 16.59 | 11.34 | 10.32 | 12.75 | |
| | 3rd | 39.48 | 24.79 | 20.87 | 28.38 | |
| | 4th | 53.90 | 27.38 | 33.47 | 38.25 | |
| Mean | | 27.85 | 16.19 | 16.46 | 20.16 | 5.01 |
| Shoot weight (g /plant) | 1st | 0.09 | 0.05 | 0.05 | 0.06 | |
| | 2nd | 0.82 | 0.52 | 0.50 | 0.63 | |
| | 3rd | 3.36 | 2.20 | 2.12 | 2.56 | |
| | 4th | 7.73 | 4.06 | 4.81 | 5.53 | |
| Mean | | 3.00 | 1.72 | 1.87 | 2.20 | 0.51 |
| Seed yield (g /m$^2$) | | 338.72 | 243.72 | 236.69 | 273.04 | 74.89 |
| Seed yield (no. /plant) | | 2306 | 830 | 574 | 1237 | 453.42 |
| Harvest index | | 0.33 | 0.30 | 0.29 | 0.31 | 0.06 |

*Seed yield*: Seed production of fat hen responded similarly to shoot weight (Table 1&2). When fat hen was planted with wheat varieties, on average 79% less seeds was produced in comparison to pure stands. Again there was a difference in response to competition from different wheat varieties. The lowest amount of seed per unit area was recorded under Alexandria followed by Tonic and the highest amount was under Baldus. Williams (16) also observed a reduced seed output when the weed was planted into a stand of kale. The harvest index was similar under different varieties. Density of the weed had also a significant effect on its seed production. The highest amount of seeds per unit area was produced under the lowest density (200 plants/m$^2$). However, the difference in seed production between densities of 400 and 600 plants/m$^2$ was negligible. The similarity in the extent of seed production between higher densities could be the result of a decrease in number of seeds per plant with increasing plant density (Table 2). Ervio (1), and Sibuga and Bandeen (15) also noticed similar seed production of fat hen under different weed densities. The harvest index was fairly constant irrespective of weed density. The seed production of fat hen was highly correlated ($r^2$=0.98) to shoot biomass of the weed.

*Conclusion:* From the present investigation it is therefore, obvious that the response of fat hen to competition from different species and that from higher number of same species are different. The experimental results showed the importance of morphological variation and seed production under intra- and inter-specific mixtures as a factor influencing the success of fat hen as an annual weed.

## ACKNOWLEDGEMENTS

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# HERBICIDAL ACTIVITY, SELECTIVITY AND MODE OF ACTION OF EK-2612: A NEW CYCLOHEXANEDIONE HERBICIDE IN RICE AND BARNYARD GRASS

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*Summary:* EK-2612, [5-(2-3-dihydro-2, 2, 4, 6, 7-pentamethyl benzofuran-5-yl)-2-[1-(allyoxyimino)butyryl]-3 hydroxy cyclohex-2-en-1-one] was synthesized and examined for post-emergence activity against barnyardgrass and rice. Its mode of action of was also studied. EK-2612 exhibited post-emergence activity against barnyardgrass and slight rice injury by foliar application. EK-2612 inhibited acetyl-CoA carboxylase activity and lipid synthesis much more in barnyardgrass than in rice. Significant electrolyte leakage was observed in barnyardgrass, but no electrolyte leakage was detected in rice.

*Keywords*: cyclohexanedione, rice, barnyardgrass

## INTRODUCTION

EK-2612, a member of cyclohexanedione family was synthesized by Korea Research Institute of Chemical Technology, Taejon, Korea. Its structure and physico-chemical properties is shown in Figure 1.

Empirical formula: $C_{26}H_{35}NO_4$
Molecular weight: 425.57
Appearance: White solid
Melting point: 85.5-87.5°C
Solubility: Easily soluble in common solvents such as acetone, alcohols, chloroform, methylene, chloride, toluene, etc.

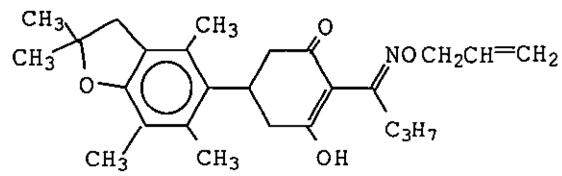


Fig. 1. Chemical structure and properties of EK-2612.

EK-2612 showed 100% herbicidal activity against crabgrass and fall panicum and 90% against barnyardgrass with no damage to crops by post-emergence application at 30 g/ha (4, 5). Its mode of action is most likely the same as sethoxydim, a cyclohexanedione, that is the inhibition of acetyl-oA carboxylase and fatty acid biosynthesis (1, 5).

The objective of this study was to determine the herbicidal activity of EK-2612 against barnyardgrass in rice and to confirm its mode of action.

## MATERIALS AND METHODS

*Plant growth study:* Rice cv. Chuchung (*Oryza sativa L.*) and barnyardgrass (*Echinochloa crus-galli* Beauv.) at 2-2.5 leaf stage were sprayed with EK-2612 at 15, 30, 60, 120 g/ha, and plant height, dry weight of plants, and chlorophyll content were measured at 12 days after treatment.

*Acetyl-CoA carboxylase assay:* Incorporation of $NaH^{14}CO_3$ into acetyl-CoA to form malonyl-CoA via acetyl-CoA carboxylase was assayed using 10-day-old rice and barnyardgrass leaves by modified methods of Stoltenberg *et al.* (6). Fresh leaf tissue was homogenized in a medium of 100 mM tricine-KOH pH 8.3, 10% glycerol, 10 mM β-mercaptoethanol, 1 mM $Na_2$ EDTA and 1 mM phenylmethyl sulfonyl fluoride. The homogenate was filtered through 4 layers of cheese cloth and centrifuged at 25,000 g for 30 minutes at 4°C. Supernatant was saturated with 10.6% $(NH_4)_2SO_4$ for 20 minutes and centrifuged at 25,000 g and supernatant was saturated with 11.3% $(NH_4)_2SO_4$ again, and centrifuged at 25,000 g for 30 minutes. The precipitate was resuspended in 10 mM tricine-KOH pH 7.8, 10% glycerol and desalted on a Sephadex G-25 column. Acetyl-CoA carboxylase activity was assayed at 35°C for 10 minutes in a volume containing 20 mM DTT, 50 mM $MgCl_2$, 20 mM ATP, 150 mM $NaH^{14}CO_3$(0.34 μCi/μmol) and 0.1 ml enzyme preparation. Reactions were initiated by addition of 20 ml 30 mM acetyl-CoA and stopped by addition of 50μl 12N HCl and radioactivity quantified by liquid scintillation spectrometer (Packard Tricarb 2300TR).

*Acetate incorporation study:* To investigate the influence of EK-2612 on lipid synthesis in rice and barnyardgrass leaves, 30 leaf discs (4 mm diameter) taken from 10-day-old rice and barnyardgrass were added to 10 ml $^{14}C$-acetate (0.1 µCi/ml) + 0.1 M potassium phosphate buffer pH 7.5 solution and 0-200 µM EK-2612 were added to the medium and incubated for 24 hours in growth chamber (25°C). After being rinsed with distilled water, the leaf discs were boiled with water-saturated butanol containing 0.005% butylated hydroxy-toluene and then homogenized and centrifuged at 15,000 g for 10 minutes. The supernatant was dried under nitrogen at 40°C water bath. This fraction was then dissolved in 0.5 ml of chloroform-methanol-water (86:14:10 v/v). A 0.2 ml aliquat of the fraction was transferred to a scintillation vial and 4 ml scintillation cocktail solution was added and radioactivity was determined using a scintillation spectrometer.

*Cellular damage:* To examine the peroxidation of cell membrane, cellular leakage was determined in rice and barnyardgrass. Eighty leaf tissue discs (4 mm diameter) were placed in a 6-cm diameter Petri dishes containing 7 ml of 1% sucrose, 1 mM 2-(N-morpholino) ethanesulfonic acid pH 6.5 with or without EK-2612 compound dissolved in acetone. The tissues were incubated in a growth chamber at 25°C in darkness for 5 days. Electrolyte leakage into the bathing medium was detected by the conductivity meter daily.

## RESULTS AND DISCUSSION

EK-2612 did not inhibit the growth of rice at 15 and 30 g/ha, but inhibited rice growth by 10 and 18% at 60 and 120 g/ha by foliar application at 3 leaf stage of rice (Table 1). On the other hand, the growth of barnyardgrass was inhibited by 74 and 84% at 60 and 120 g/ha, respectively.

Chlorophyll content in barnyardgrass was reduced greatly with the increase of EK-2612 concentrations, but chlorophyll content in rice was not affected by EK-2612 (Figure 1). Gealy and Slife (2) indicated that chlorophyll contents in corn

Table 1. Effect of EK-2612 foliar application on plant height and dry weight of rice and barnyardgrass 12 days after treatment.

| Rate | Rice | | | Barnyardgrass | | |
|---|---|---|---|---|---|---|
| (g/ha) | Plant height (cm) | Dry weight (mg/plant) | Inhibition (%) | Plant height (cm) | Dry weight (mg/plant) | Control (%) |
| 15 | 26.4 | 22.4 | 4 | 15.5 | 6.8 | 32 |
| 30 | 25.4 | 22.1 | 6 | 12.2 | 5.3 | 47 |
| 60 | 26.6 | 21.1 | 10 | 8.5 | 2.8 | 74 |
| 120 | 25.4 | 19.1 | 18 | 6.4 | 1.7 | 84 |
| Check | 28.4 | 23.3 | - | 21.7 | 9.6 | - |

was significantly reduced by BAS 9052, a cyclohexanedione and that this effect was due to the damage of chloroplast and photo-oxidation of chlorophyll. In rice and barnyardgrass, acetyl-CoA carboxylase activity was inhibited by EK-2612 and the response to inhibition was linear with increasing EK-2612 concentrations (Figure 2). However, acetyl-CoA carboxylase was more sensitive to EK-2612 in barnyardgrass than in rice.

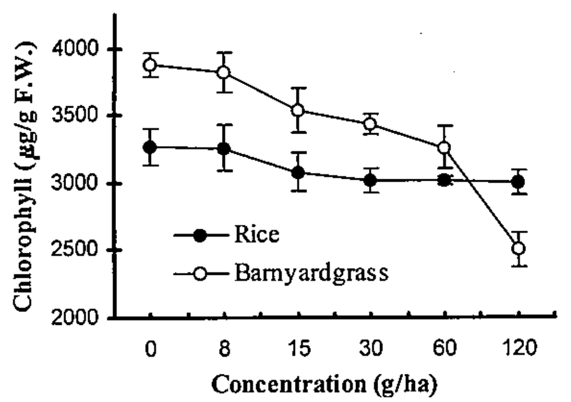


Fig. 1. Effect of EK-2612 on chlorophyll content in rice and barnyardgrass leaves 5 days after treatment

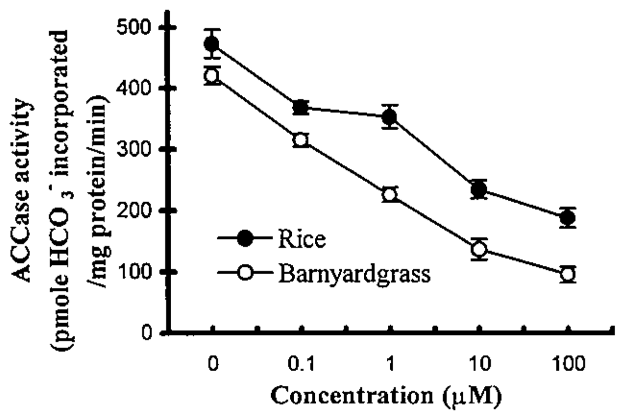


Fig. 2. Effect of EK-2612 on acetyl-CoA carboxylase activity in rice and barnyardgrass

Total lipid synthesis, as measured by incorporation of $^{14}C$-acetate, was reduced by 70% in barnyardgrass and 50% in rice with 200 µM EK-2612 treatment (Figure 3). This was similar to the results of haloxyfop and diclofop-methyl effects on lipid synthesis in corn (1, 3).

Cellular leakage did not occur until 3 days of incubation for rice and barnyardgrass treated with EK-2612 (Figure 4). However, cellular leakage from both species began to increase 3 days after incubation and magnitude of cellular leakage changes was much higher in barnyardgrass than in rice. These results indicate that EK-2612 showed selectivity between rice and barnyardgrass and mode of action of EK-2612 may be primarily attributed to the inhibition of acetyl-CoA carboxylase and lipid synthesis, and also the damage all membrane by perodixation.

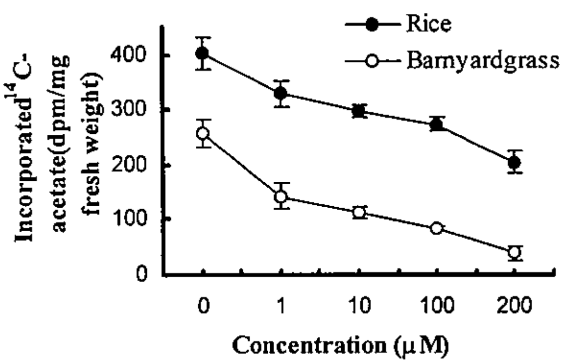


Fig. 3. Effect of EK-2612 on $^{14}C$-acetate incorporation into lipid in rice and barnyardgrass leaf

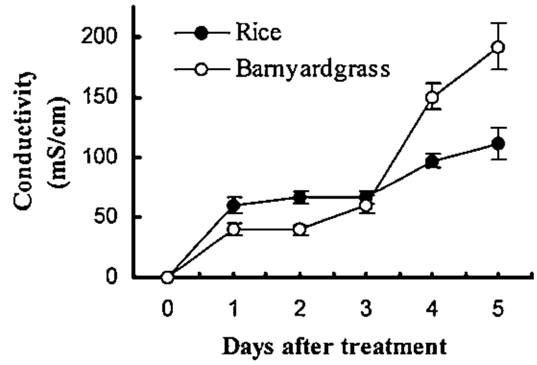


Fig. 4. Effect of EK-2612(I50) on electrolyte leakage from rice and barnyardgrass

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# EFFECTS OF FIELD VARIABLES ON THE EFFICACY OF THE NEW HERBICIDE LGC-40863

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*Summary*: Experiments were conducted to evaluate the effects of field variables including temperature, rainfast, flooding depth, spray volume, and adjuvants on the efficacy of the new post-emergence rice herbicide, LGC-40863 (benzophenone *O*-[2,6-bis[(4,6-dimethoxy-2-pyrimidinyl)oxy]benzoyl]oxime). The efficacy of LGC-40863 on barnyardgrass (*Echinochloa crus-galli* L. Beauv.) was greater at higher temperature. A rain-free period of 6 h after LGC-40863 application was required to obtain excellent weed control (>95 %). The efficacy of LGC-40863 was little affected by flooding up to the depth of 60% of plant height, and by varying spray volume from 125 to 1,000 L/ha. Addition of adjuvants increased efficacy on barnyardgrass by 10 to 55%, and the level of enhancement was dependent on adjuvant concentration from 0.025 to 0.1%.

*Keywords*: LGC-40863, pyribenzoxim, rice, field variables

## INTRODUCTION

LGC-40863 (proposed common name: pyribenzoxim) is a new post emergence herbicide in pyrimidinyloxybenzoate chemistry (figure 1) (1). The herbicide is selective to rice, wheat and turfgrass, and controls various grass and broadleaf weeds (2). In rice, the herbicide controls *Echinochloa crusgalli*, *Echinochloa colona*, *Polygonum hydropiper*, *Aeschynomene indica*, *Bidens frondsa*, and *Sagittaria trifolia*. In particular, the herbicide controls barnyardgrass across a wide growth stage from the 1- to 6-leaf stage. The application rate is 30 to 40 g ai/ha when treated alone, or 15 to 30 g/ha when treated with pendimethalin (2). The herbicide inhibits acetolactate synthase (ALS) in a non-competitive manner similar to chlorsulfuron (4). Rice selectivity was based on recovery of *in vivo* ALS activity after 24 h of herbicide application, which did not occur in barnyardgrass (3).

It is well known that the efficacy of post-emegence herbicide can be affected by various environmental and physical factors (5, 6, 7, 8, 9). In this study, we examined the effects of several field variables on the efficacy of LGC-40863.

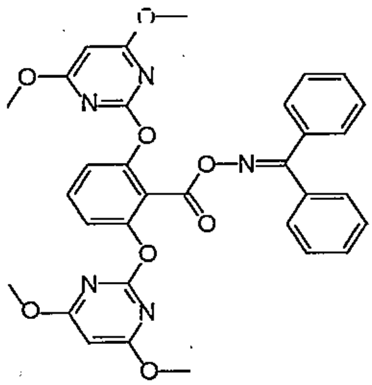

Fig. 1: Chemical structure of LGC-40863

## MATERIALS AND METHODS

*Plants preparation and herbicide application*: Barnyardgrass or Indian jointvetch (*Aeschynomene indica* L.) were grown for 2 weeks in separate pots (surface area: 200 cm$^2$) containing sterilized silty loam soil (43% sand, 43% silt, and 14% clay) in a greenhouse maintained at 30 ± 3 °C during the day and 25 ± 3°C at night. Ten plants with uniform growth were left in each pot. LGC-40863, formulated to 1% emulsifiable concentrate (EC), was applied to barnyardgrass at the 3-leaf stage with a $CO_2$-pressured belt-driven sprayer equipped with an 8001 flat fan nozzle adjusted to deliver 1,000 L/ha at 270 kPa except in the experiment on spray volume. Data were reported as percent control based on fresh weight measured 3 weeks after application. The experiments consisted of three replicates, and the data were subjected to analysis of variance.

*Temperature*: The range of ambient temperature tested with LGC-40863 activity on barnyardgrass were 16/10, 22/16, 28/22, 34/28 °C (day/night) and day length was 14 h. This experiment was conducted in growth chambers providing 10,000 lux using fluorescent and metal halide lamps. LGC-40863 was applied at two rates: 20 and 30 g/ha.

*Rainfastness*: Barnyardgrass and Indian jointvetch was treated with LGC-40863 at 30 g/ha. The pots containing the treated plants were placed in a square of 1 m by 1 m. Rain simulation was made by spraying 5 L of water into the square with a $CO_2$-pressurized hand sprayer equipped with an 8004 nozzle at 0.5, 2, 4, 6, 8, 12, or 24 h after herbicide application.

*Flooding depth*: Barnyardgrass at the 3-leaf stage (plant height: 10 cm) was flooded to a depth of 0, 2, 4, 6, 8, or 10 cm 1 day before application. LGC-40863 was sprayed at 30 and 50 g/ha in each flooding conditions.

*Spray volume*: LGC-40863 30 g/ha was sprayed on barnyardgrass and Indian jointvetch with various spray volumes ranging from 125 to 2,000 L/ha. Different spray volumes were obtained by adjusting the moving speed of the nozzle from 4 to 64 m/min.

*Adjuvant concentration*: A non-ionic adjuvant (alkylarylpolyethoxylate and sodium salt of alkylsulfonated alkylate) was added at 0, 0.025, 0.05, or 0.1 % (w/w) in the spray solution containing LGC-40863 at 30 g/ha.

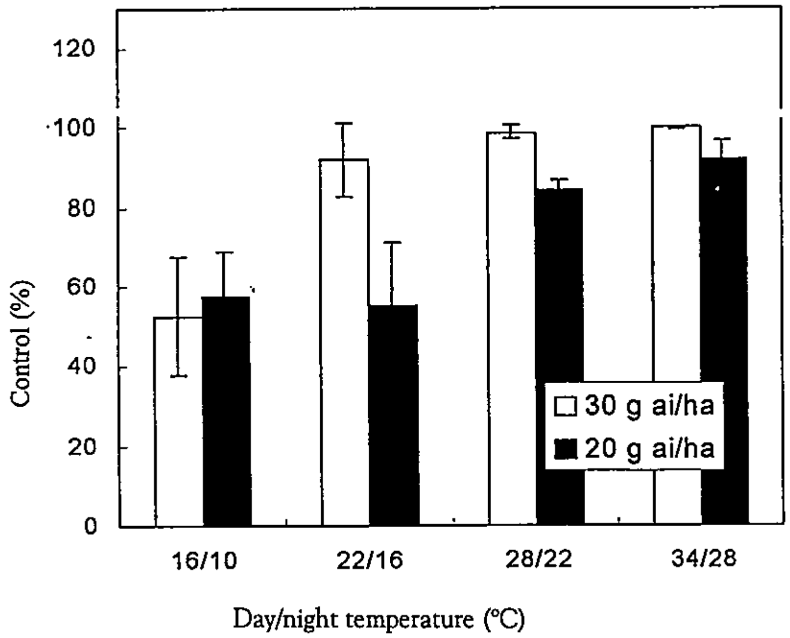


Fig.2: Effect of temperature on the efficacy of LGC-40863. Data points represent mean of 3 replicates ± SD

## RESULTS AND DISCUSSION

*Temperature*: Efficacy decreased significantly in the lowest temperature regime (16/10°C, day/night) at the recommended rate (30 g/ha), and from the next lowest temperature regime (22/16°C, day/night) at 20 g/ha (Figure 2). LGC-40863 efficacy tended to be greater at higher temperature than at lower temperature.

*Rainfast*: When rainfall occurred 6 h after application or afterward, there was no difference in weed control efficacy; however, rainfall during the early 6 h after application decreased the efficacy of LGC-40863 (Figure 3). These data indicated that a rain-free period of 6 h after LGC-40863 application was required to obtain complete weed control (>95 %). Reduction of control efficacy due to early rainfall was greater in barnyardgrass than Indian jointvetch. This species difference could be due to differential uptake rates or leaf surface structure.

*Flooding depth*: Barnyardgrass control was little affected by flooding up to the depth of 60% of the plant height, however it decreased dramatically when the shoot was flooded more than 80% of the plant height (Figure 4). These data suggest that at least 40% of the upper foliage needs to be covered by spray to obtain optimum control.

*Spray volume*: Weed control efficacy was not affected by varying spray volume from 125 up to 1,000 L/ha except for an extraordinary high spray volume of 2,000 L/ha (Figure 5). This suggests that the herbicide will provide consistent weed control across widely diverse spray conditions in different countries.

*Adjuvant concentration*: With increased adjuvant concentration from 0.025 to 0.1%, LGC-40863 efficacy increased by 28 to 55% and 10 to 15% at 20 and 30 g ai/ha, respectively (Fig. 4). This result suggests that addition of adjuvant can increase control efficacy or reduce the LGC-40863 rates required for optimum weed control.

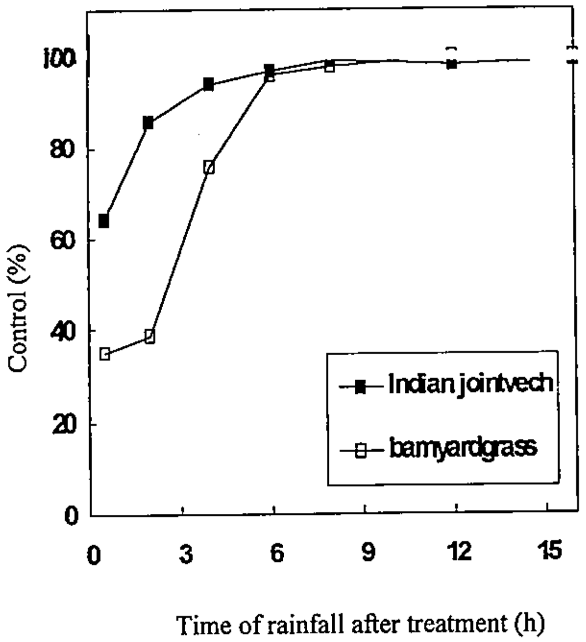


Fig. 3: The effect of simulated rainfall timing on the efficacy of LGC-40863

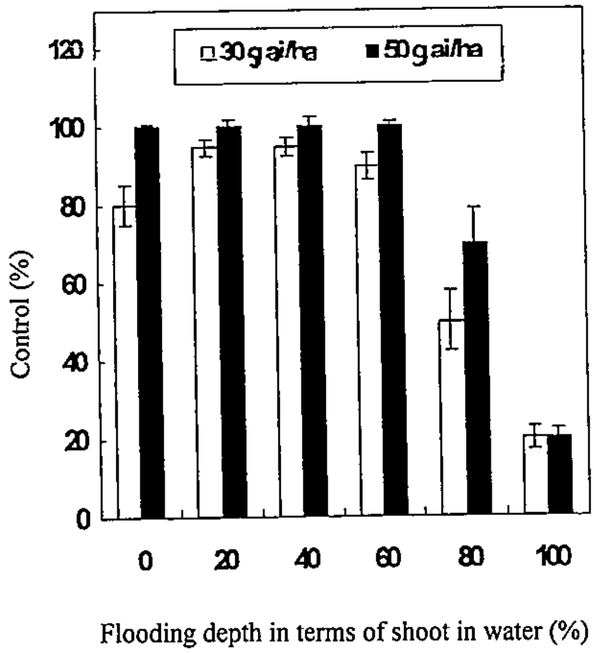


Fig. 4: The effect of flooding depth on barnyard -grass control by LGC-40863

LGC-40863 is a new post-emergence rice herbicide. The efficacy of post-emergence herbicides can be influenced by various environmental and physical factors such as temperature, rainfall, relative humidity, spray volume, and kind and concentration of adjuvants. Bentazon activity was greater when temperature and relative humidity were higher for redroot pigweed (5). Similarly, LGC-40863 controlled barnyardgrass more effectively at higher temperature. This result may be due to increased absorption and translocation of LGC-40863 at higher temperature. The time interval between herbicide application and rainfall needed for adequate weed control varies among herbicides. Bryson reported that seedling and rhizome johnsongrass control with selective POST herbicide was reduced when rainfall occurred within 4 h after application (6). In greenhouse washoff studies, Richard (10) reported that asulam needed longer than 24 h of rain-free period to maximize johnsongrass control. LGC-40863 required a rain-free period of 6 h to obtain weed control of more than 95 %. Therefore, LGC-40863 appears to have medium rainfastness compared to other post-emegence herbicides. Spray volume is inversely related to herbicide concentration. Greater concentration of herbicide can influence efficacy of POST herbicide (7). Increased efficacy of glyphosate, fluazifop-butyl, and sethoxydim is associated with lower spray volumes. However, in the case of DPX-PE350, spray volume had little effect on the efficacy (8). The efficacy of LGC-40863 was not affected by varying spray volume from 125 up to 1,000 L/ha (Fig. 3) similar to DPX-PE350. Adjuvants are commonly used to enhance herbicide activity (8, 9). Similar to other POST herbicides, addition of an adjuvant increased LGC-40863 efficacy significantly. This result suggested that addition of a suitable adjuvant can either increase the efficacy or reduce the use rate of LGC-40863.

Collectively, these data provide fundamental information of possible field variation of LGC-40863 performance in rice.

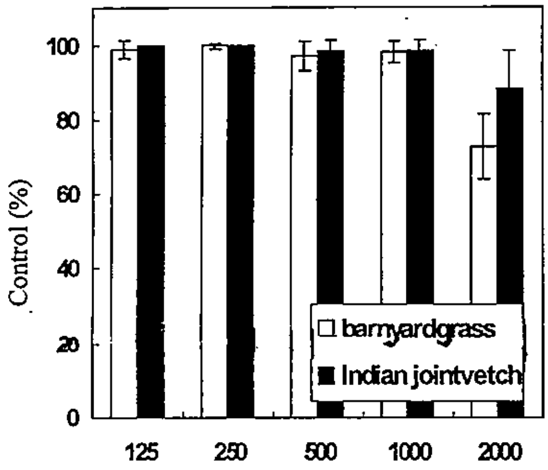


Fig. 5: Effect of spray volume on the efficacy of LGC-40863

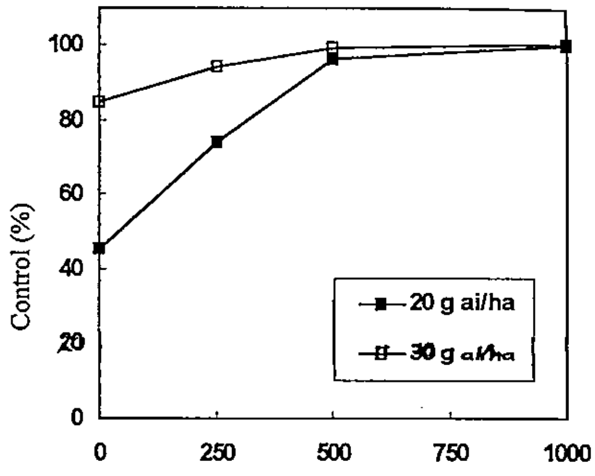


Fig. 6: The effect of non-ionic adjuvant on barnyard-grass control by LGC-40863

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# AC 322,140 AND COMBINATIONS: HERBICIDAL ACTIVITY AGAINST *MONOCHORIA KORSAKOWII* REG. ET MACCK

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*Summary*: AC 322,140 , UTOPIA (AC 140/KPP-314 in 0.2/1.5% G), and NEBIROS (AC 140/CH-900/dymron in 0.6/3/6% G) provided excellent control of *M. korsakowii* in a greenhouse test. Pre-emergence and post-emergence treatments were superior to FUJIGRASS (DPX-84/esprocarb in 0.25/7% G) and ACT (NC-311/mefenacet in 0.07/3.5% G) . AC 322,140 alone gave excellent control of *M. korsakowii* at pre-emergence. AC 322,140 control was superior to DPX-84, NC-311, KPP-314, CH-900, esprocarb and mefenacet. In field trials from 1992 to 1996, UTOPIA provided excellent control of *M. korsakowii* from NEBIROS controlled *M. korsakowii* at pre-emergence and post-emergence 1.5L treatments. AC 322,140 controlled M. korsakowii at pre-emergence and post-emergence-1.5L treatments.

*Keywords*: AC 322 140, new herbicide, *Monochoria* control, rice herbicide

## INTRODUCTION

AC 322,140 (cyclosulfamuron) is a new rice herbicide being developed by American Cyanamid Company. Weed control spectrum and characteristic activity of AC 322,140 were reported at the 14th APWSS in Brisbane (1, 2). This paper describes the biological performance of AC 322,140 and combinations such as UTOPIA (AC 322,140/KPP-314) in 0.2/1.5% G and NEBIROS (AC 322,140/CH-900/dymron) in 0.6/3/6% G against *Monochoria korsakowii* (MOOKO) in greenhouse and field trials in Japan. The field use rates of UTOPIA are 60/450 and NEBIROS at 60/300/600 g ai/ha of their formulated combinations.

## MATERIALS AND METHODS

*Greenhouse trials*: Greenhouse testing was conducted at Tahara Agricultural Center using a loamy soil in 0.01 pots. Treatments were replicated three times. Seeds of MOOKO were collected in 1995 from a field trial site in Hokkaido. Technical grade AC 322,140, KPP-314, CH-900 and the granular products, UTOPIA and NEBIROS, were tested at pre-emergence and post-emergence (at 1 leaf stage) of MOOKO. Weed control was assessed at various times after application.

*Field trials*: AC 322,140 as 0.2% G, UTOPIA as 0.2/1.5% G and NEBIROS as 0.6/3/6% G, were field tested in paddy rice from 1992 to 1996. All treatments were replicated 3 times with a plot size of 2 x 3 m. Treatments were made by hand post-transplant to rice at pre-emergence and post-emergence to weed from 0 to 13 DAT (days after transplanting). Commercially available products were used as references. Plots were visually assessed at various times during the growing season.

## RESULTS AND DISCUSSION

*Greenhouse trials*: AC 322,140, applied at pre-emergence, at 60 g/ha (standard dosage) controlled 97% of MOOKO. Control was superior to DPX-84 at 75 g/ha and NC-311 at 21 g/ha. (Table 1).

Table 1. Activity of AC 322,140 against *M. korsakowii* at pre-emergence.

| | Control of MOOKO at 54 days after application (%) | | |
|---|---|---|---|
| Dosage Standard X | AC 322,140 Tech. 60 g/ha. | DPX-84 Tech. 75 g/ha. | NC-311 Tech. 21 g/ha. |
| X 1 | 97 | 78 | 83 |
| X ½ | 93 | 30 | 33 |
| X ¼ | 84 | 20 | 0 |
| X 1/10 | 67 | 0 | 0 |

UTOPIA gave 98% control at 0.1x use rate at pre-emergence and 100% at 0.25x rate at post-emergence (1 leaf stage) of MOOKO. NEBIROS at 0.25x use rate gave 98% MOOKO control at pre-emergence and 100% at 0.5x rate at post-emergence. UTOPIA and NEBIROS are more active at pre-emergence than at post-emergence (1 leaf stage). These products were more active than FUGIGRASS and ACT (Table 2 and 3).

Table 2. Activity of UTOPIA and NEBIROS against MOOKO at pre-emergence.

| | Control of MOOKO at 62 days after application (%) | | | |
|---|---|---|---|---|
| Dosage Standard X | UTOPIA 60/450 g/ha. | NEBIROS 60/300/600 g/ha. | FUJIGRASS 75/2100 g/ha. | ACT 21/1050 g/ha |
| X 1 | 100 | 100 | 85 | 98 |
| X 1/2 | 100 | 98 | 50 | 78 |
| X 1/4 | 99 | 98 | 33 | 50 |
| X 1/10 | 98 | 90 | 20 | 30 |

FUJIGRASS: DPX-84/esprocarb at 0.25/7% G
ACT: NC-311/mefenacet at 0.07/3.5% G

Table 3. Activity of UTOPIA and NEBIROS against MOOKO at post-emergence(1 leaf stage).

| | Control of MOOKO at 47 days after application (%). | | | |
|---|---|---|---|---|
| Dosage Standard X | UTOPIA 60/450 g/ha. | NEBIROS 60/300/600 g/ha. | FUJIGRASS 75/2100 g/ha. | ACT 21/1050 g/ha |
| X 1 | 100 | 100 | 98 | 99 |
| X 1/2 | 100 | 100 | 82 | 97 |
| X 1/4 | 100 | 92 | 82 | 75 |
| X 1/10 | 83 | 78 | 43 | 13 |

Grass herbicides used in UTOPIA and NEBIROS showed good biological activity against MOOKO. KPP-314 controlled MOOKO 100% at 0.25x dosage at pre-emergence and CH-900 at 0.5x dosage gave 97% (Table 4).

Table 4. Activity of grass herbicide against MOOKO at pre-emergence.

| | Control of MOOKO at 54 days after treatment (%). | |
|---|---|---|
| Dosage Standard X | KPP-314 Tech. 450 g/ha. | CH-900 Tech. 300 g/ha. |
| X 1 | 100 | 99 |
| X 1/2 | 100 | 97 |
| X 1/4 | 100 | 86 |
| X 1/10 | 94 | 40 |

*Field trials*: UTOPIA at 60/450 g/ha provided 100% control of MOOKO from 1992 to 1996 applied O DAT and 5 DAT in 1996 (Table 5).

AC 322,140 in 0.2% G at 60 g/ha also controlled 97-100% of MOOKO during these five years applied 0, 5, and 13 DAT. NEBIROS at 60/300/600 g/ha gave 95-100% control of MOOKO in these trials 5 DAT and 13 DAT. Field performance of UTOPIA and NEBIROS against MOOKO are better than WOLF ACE and AWARD at 0 DAT and FUGIGRASS at 13 DAT.

Table 5. Control of MOOKO with UTOPIA, NEBIROS and AC 322,140 treated at pre-emergence to post-emergence in paddy field from 1992-1996 at Hokkaido, Japan.

| | Rate | Application | Control of MOOKO at 2.5-3 months after application (%). | | | | |
|---|---|---|---|---|---|---|---|
| Treatment | g/ha | Timing | 1992 | 1993 | 1994 | 1995 | 1996 |
| UTOPIA 15 0.2/1.5%G | 60/450 | 0 DAT | 100 | 100 | 100 | 100 | 100 |
| AC 322,140 0.2%G | 60 | " | 100 | 100 | | | 97 |
| WOLF ACE 25 | 75/1500/450 | " | | | | | 78 |
| AWARD 1.7/12/27.5%G | 85/600/1375 | " | | | 100 | 73 | |
| NEBIROS 0.6/3/6%G | 60/300/600 | 5 DAT | 99 | | 100 | 100 | 98 |
| UTOPIA 15 0.2/1.5%G | 60/450 | " | | | | | 100 |
| AC 322,140 0.2%G | 60 | " | 100 | 100 | | 100 | 100 |
| WOLF ACE 25 | 75/1500/450 | " | 100 | 100 | | 99 | 97 |
| Mefenacet 4%G | 1200 | " | | | | 33 | |
| NEBIROS 0.6/3/6%G | 60/300/600 | 13 DAT | 100 | | | 95 | 100 |
| AC 322,140 0.2%G | 60 | " | 100 | 100 | | | 100 |
| WOLF ACE 25 | 75/1500/450 | " | 99 | 100 | | 83 | 97 |
| FUJIGRASS | 75/2100 | " | | | | | 89 |
| Mefenacet 4%G | 1200 | " | | | | 47 | 63 |

WOLF ACE 25: DPX-84/thiobancarb/mefenacet in 0.25/5/1.5% G
AWARD: imazosulfuron/pyributicarb/dymron in 1.7/12/27.5 (w/v)% SC

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# VEGETATION MANAGEMENT BY KIH-2023 IN RICE LEVEES, AND HIGHWAY AND RAILROAD RIGHT-OF-WAYS.

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*Summary* : KIH-2023, sodium 2, 6-bis [ ( 4, 6-dimethoxypyrimidin-2-yl ) oxy ] benzoate at the rate of 150 g ai/ha pre-mixed with non-ionic surfactant reduced vegetative growth of weeds such as *Imperata cylindrica* , *Digitaria adscendens* , *Miscanthus sinensis* and *Artemisia princeps* . The growth reduction persisted for 50 days after application of KIH-2023 when applied 5-10 days after mowing (at 10-20 cm of plant height). Also, KIH-2023 killed a wide range of weed species such as *Solidago altissima*, *Persicaria lapathifolia*, *Aeschynomene indica*, *Paspalum distichum* and *Echinochloa crus-galli* which grew in rice levees or highway and railroad right-of-ways. The test results indicated that KIH-2023 can reduce the frequency of mowing in paddy rice levees, and highway and railroad right-of-ways.

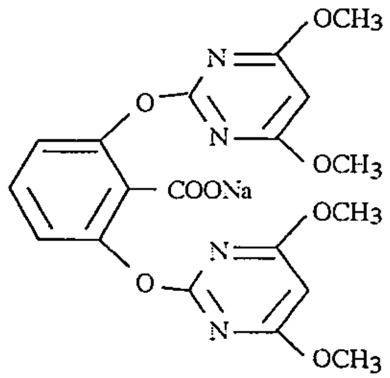
*Keywords*: KIH-2023, bispyribac-sodium, growth retardant

## INTRODUCTION

In Japan, vegetation management in rice levees is very laborious because it is largely a hand operation utilizing motorized rotary trimmers with metal blades. These trimmers obviously pose a risk for the workers. Non-selective herbicides have been used to substitute for mowing but these often kill all of the weeds leaving the rice levee surface exposed. Rice levees without plants are easily eroded by rainfall and water waves. Drift of the spray solution from these non-selective herbicides also pose risk of injury to the adjacent crop. There is a need for levee management methods which are less laborious and more convenient and safer for the worker and to adjacent crops.

KIH-2023 is a new herbicide discovered and under development by Kumiai Chemical Industry Co., Ltd. for use at post-emergence in direct seeded rice (Fig. 1). From our various studies, we found that it may be possible to use KIH-2023 in lieu of mowing as the vegetation management agent in rice levees, and highway and railroad right-of-ways. This paper describes the biological properties of KIH-2023 as a growth retardant obtained from greenhouse and field trials.

Structural formula :




Common name : bispyribac-sodium ( ISO proposed )
Chemical name (IUPAC) : Sodium 2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate

Fig. 1. Chemical structure and names of KIH-2023

## MATERIALS AND METHODS

All trials were conducted in Shizuoka Prefecture, Japan in 1994-1996. A 3% LC formulation (30 g a.i./L) pre-mixed with nonionic surfactant was applied to the foliage in water at 1000 L/ha utilizing a CO2-pressurized sprayer. Field experiments (trials 2 to 5) were conducted from May to October along the road side of KUMIAI Life Science Research Institute KAKEGAWA experimental field. Plots consisted of 4 to 20 m² blocks and were replicated twice.

*Greenhouse test*: Test weeds were grown in a greenhouse under upland conditions. The test soil was a clay loam. KIH-2023 at 90 to 300 g a.i./ha was applied to three replications of weeds growing in 10 by 10 cm pots at the growth stages shown in Table 1 and 2. Herbicidal effect was evaluated visually 30 days after application using a scale of zero to ten (zero= no effect, ten = plant death).

*Field trial on Solidago altissima growth*: KIH-2023 was applied at 150 g a.i./ha to 20-cm high *Solidago altissima* plants. Plant height to the nearest 0.5 cm were measured and recorded every 10 days after application.

*Field trial on Artemisia princeps growth*: KIH-2023 was applied at 150 g a.i./ha to 30-cm high *Artemisia princeps* plants. Data measurement and records were the same as for trial 2.

*Field trial on Imperata cylindrica growth with or without mowing before application*: KIH-2023 was applied at 150 g a.i./ha to plots five days after mowing having 25-cm high *Imperata cylindrica* plants or to plots not mowed having 22-cm high *Imperata cylindrica* plants. Data measurement and records were the same as for trial 2.

*Field trial on Digitaria adscendens growth with or without mowing before application*: KIH-2023 was applied at 150 g a.i./ha to plots 10 days after mowing having 15-cm high *Digitaria adscendens* plants or to plots not mowed having 15-cm high *Digitaria adscendens* plants. Data measurement and records were the same as for trial 2.

## RESULTS AND DISCUSSION

*Herbicidal effect of KIH-2023*: KIH-2023 killed the troublesome paddy rice grasses *Echinochloa crus-galli* and *Paspalum distichum* and suppressed the growth of *Digitaria adscendens* and *Imperata cylindrica* which are primary grasses infesting rice levees (Table 1). The annual broadleaf weeds *Aeschynomene indica* and *Persicaria lapathifolia* were killed by KIH-2023 and the tops of the biennial weeds *Erigeron canadensis* and *Erigeron floribundus* were burned down, but the plants recovered (Table 2).

Table 1. Effect of KIH-2023 on the control of grass weeds 30 days after foliar application.

| Gramineous weed | Plant height (cm) at application | Rate (g a.i./ha) 90 | 150 | 300 |
|---|---|---|---|---|
| *Digitaria adscendens* | 30 | 4.0 | 7.0 | 8.0 |
| *Imperata cylindrica* | 25 | 3.5 | 4.0 | 5.0 |
| *Cynodon dactylon* | 13 | 4.0 | 8.0 | 8.0 |
| *Echinochloa crus-galli* | 25 | 10.0 | 10.0 | 10.0 |
| *Setaria viridis* | 30 | 8.0 | 10.0 | 10.0 |
| *Paspalum distichum* | 30 | 10.0 | 10.0 | 10.0 |
| *Lolium mutiflorum* | 15 | 0.0 | 2.0 | 4.0 |
| *Eleusine indica* | 20 | 2.5 | 4.5 | 5.0 |

evaluation scale : 0=no effect, 10=plant death

Table 2. Effect of KIH-2023 on the control of broadleaf weeds 30 days after foliar application.

| Broadleaf species | Plant height (cm) at application | Rate (g a.i./ha) 90 | 150 | 300 |
|---|---|---|---|---|
| *Erigeron canadensis* | rosette | 6.6 | 7.0 | 8.5 |
| *Erigeron floribundus* | rosette | 7.0 | 8.6 | 9.8 |
| *Trifolium repens* | 10 | 9.0 | 9.8 | 10.0 |
| *Persicaria lapathifolia* | 25 | 10.0 | 10.0 | 10.0 |
| *Vicia angustifolia* | 10 | 9.8 | 9.8 | 9.8 |
| *Cerastium glomeratum* | 20 | 9.8 | 9.8 | 9.8 |
| *Aeschynomene indica* | 50 | 10.0 | 10.0 | 10.0 |
| *Xanthium orientale* | 10 | 9.8 | 9.8 | 9.8 |

evaluation scale : 0=no effect, 10=plant death

These greenhouse results suggest that KIH-2023 at 150 g a.i./ha could change a large population consisting of grass and broadleaf weed species on rice levees and highway and railroad rights-of-ways to a population consisting mainly of the grass species *Digitaria adscendens* and *Imperata cylindrica* growth reduced more than 40 percent (Table 1).

*Field trial on Solidago altissima growth*: Thirty days after KIH-2023 application at 150 g a.i./ha, the above ground shoots of *Solidago altissima* were killed (Fig. 1). However this troublesome weed in highway and railroad right-of-ways in Japan then began to recover from this initial injury by growth from subterranean stems.

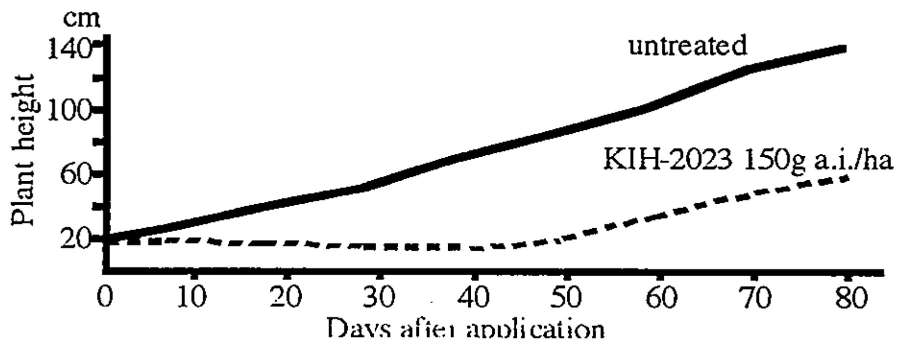



Figure 1. The change in *Solidago altissima* plant height after KIH-2023 application.

*Field trial on Artemisia princeps growth*: The plant height of *Artemisia princeps*, another weed common to highway and railroad right-of-ways, was reduced by KIH-2023 at 150 g a.i./ha (Figure 2). Thirty days after treatment the terminals were killed and growth arrested. It was necessary to mow the untreated plot 30 days after treatment initiation while the plots treated with KIH-2023 lasted for more than 50 days before mowing might be needed.

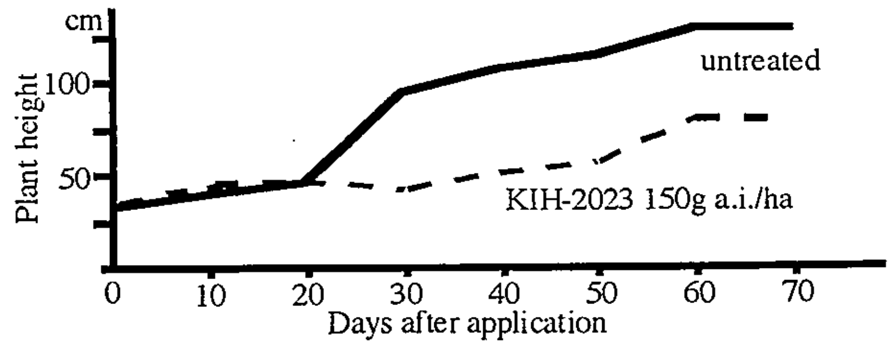



Figure 2. The change of *Artemisia princeps* plant height after KIH-2023 application.

*Field trial on Imperata cylindrica growth with or without mowing before application*: The plant height of *Imperata cylindrica* which was not mowed but treated with 150 g a. i. KIH-2023/ha did not increase for 30 days after application (Figure 3). If *Imperata cylindrica* plots were mowed five days before KIH-2023 application, plant height did not increase for more than 50 days after application (Figure 4). This indicates KIH-2023 would be an excellent treatment for paddy rice levees and highway and railroad right-of-ways.

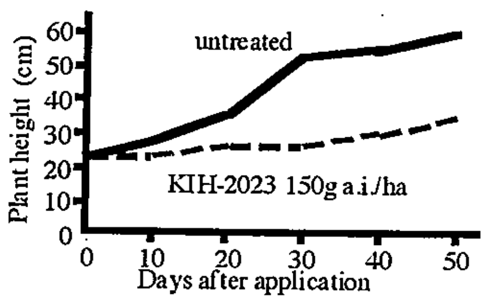



Figure 3. The change of *Imperata cylindrica* plant height after KIH-2023 application without mowing before application.

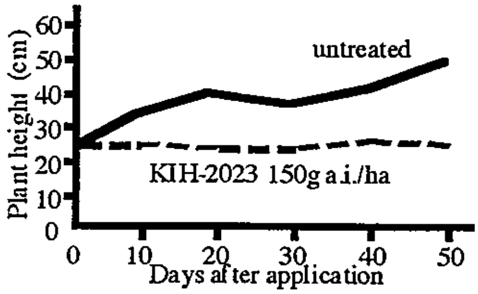



Figure 4. The change of *Imperata cylindrica* plant height after KIH-2023 application with mowing five days before application.

*Field trial on Digitaria adscendens growth with or without mowing before application*: KIH-2023 applied without mowing before application was not very effective in preventing the growth of *Digitaria adscendens* (Figure 5). Thirty days after application the KIH-2023 treated plots measured 50 cm and the untreated 60 cm. If the *Digitaria adscendens* plots were mowed 10 days before KIH-2023 application, plant height did not increase for 40 days after application (Figure 6). For KIH-2023 to effectively keep the plant height of *Digitaria adscendens* reduced will require mowing before application.

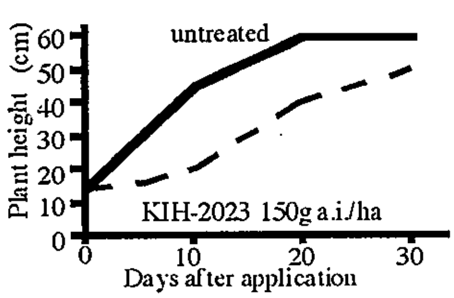



Figure 5. The change of *Digitaria adscendens* plant height after KIH-2023 application without mowing before application.

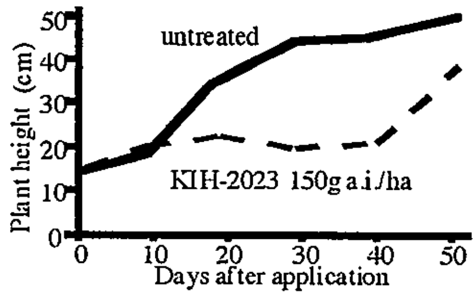



Figure 6. The change of *Digitaria adscendens* plant height after KIH-2023 application with mowing 10 days before application.

## CONCLUSIONS

Under greenhouse conditions, KIH-2023 applied post-emergence at 90-300 g a.i./ha killed *Echinochloa crus-galli* and *Paspalum distichum*, six broadleaf weed species, and suppressed the growth of other gramineous species. KIH-2023 applied post-emergence at 150 g a.i./ha killed or prevented plant height increase of *Solidago altissima* and *Artemisia princeps* for 30-40 days after application. KIH-2023 applied post-emergence at 150 g a.i./ha with mowing 5-10 days before application effectively prevented plant height increase of *Imperata cylindrica* and *Digitaria adscendens* for 40-50 days after application. Mowing before KIH-2023 post-emergence application was an effective way to keep plant height suppressed for a long period. KIH-2023 applied post-emergence can be used to reduce the frequency of mowing and maintenance requirements of paddy rice levees, and highway and railroad rights-of-ways.

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# TRINEXAPAC-ETHYL: A NEW PLANT GROWTH REGULATOR TO INCREASE HARVEST TIME FOR OPTIMAL SUGAR CONTENT IN SUGARCANE

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*Summary*: Trinexapac-ethyl was evaluated for sugar increase on six sugarcane varieties in Chuping and Padang Terap in Malaysia and Lampung in Indonesia. In all trials, trinexapac-ethyl consistently increased sugar yield of all sugarcane varieties without negative effect on juice quality, fiber content and cane weight. Trinexapac-ethyl had no negative effect on tiller production, plant height and stalk diameter in the following ratoon. Trinexapac-ethyl reduced cane height by shortening the last few internodes; this reduced the amount of vegetative trash at harvesting. In conclusion, trinexapac-ethyl increased the yield of sugar while extending the harvesting time of sugarcane to allow flexibility in deploying seasonal field labour.

*Keywords*: trinexapac-ethyl, sugarcane ripening.

## INTRODUCTION

There are some 22'000 and 1'600'000 ha of sugarcane (*Saccharum* spp.) in Malaysia and Indonesia, respectively. Yield enhancement has been largely the results of intensive breeding and agronomic studies (e.g., fertilization) in-house. However, sugarcane plantations have also tried plant growth regulators such as ethrel and glyphosine and herbicides such as fluazifop (butyl ester) and glyphosate (isopropyl amine) to increase the ripening and, thus, sugar content. The results with these plant growth regulators have been inconsistent while herbicides are known to have undesirable side-effects on subsequent ratoon cane and other neighbouring crops (3, 5, 6).

Trinexapac-ethyl is a new cyclohexandione class of plant growth regulators (4). It was discovered by Ciba-Geigy Ltd. and has been developed for use as an anti-lodging agent in cereals and rapeseed in Europe (2). It is being developed as MODDUS 250 EC for sugar increase in sugarcane in Malaysia, Indonesia and Latin America. In this paper, we report the results of trinexapac-ethyl as the state-of-the-art ripener in sugarcane in Malaysia and Indonesia.

## MATERIALS AND METHODS

Field trials were conducted in collaboration with sugarcane plantations between 1994 and 1996. In Chuping, Perlis, Malaysia, the collaborator was the Agricultural Research Division of Kilang Gula Felda Perlis Sdn. Bhd. In Padang Terap, Kedah, Malaysia, we worked with the Agricultural Research Department of Gula Padang Terap Bhd. Our collaborator in Katabumi, Lampung, Indonesia was PG Bungamayang.

*Replicated, small-plot trials*: In Chuping, trinexapac-ethyl at 300 g a.i./ha was compared to glyphosate at 400 and 800 g a.e./ha in a split-plot design in three replicates with varieties as the main plots and treatments as the sub-plots. The varieties were TC 1 and TC 4 at 9.25 months at application on 3 November, 1994. The plot size was 4 rows by 10 m of cane (54.9 $m^2$). The products were applied at 600 L/ha with a flat-fan nozzle attached to a knapsack sprayer. Cane juice was measured for pol (%) which reflected the amount of sugar in the juice at 2 weeks before application (WBA) and 0, 2, 4, 6, 8 and 10 weeks after application (WAA). Plant height was measured at 0, 2, 4, 6, 8 and 10 WAA while cane fibre at 0, 6 and 10 WAA. In addition, growth of the following ratoon crop was monitored for tiller production, plant height and stalk diameter at 8 months from germination of the ratoon.

In a follow-up trial in Chuping, trinexapac-ethyl at 100 and 200 g/ha was compared to glyphosate at 600 g/ha in a split-plot design in two replicates on variety TC 4. This time, the main plots were sites with different levels of organic matter while the sub-plots were the products. The plot size was 2 rows by 10 m of cane (27.4 $m^2$). At application on 17 March, 1995, TC 4 was 9 months old. The products were applied at 600 L/ha with a flat-fan nozzle attached to a knapsack sprayer. Cane juice was measured for pol (%) at 0, 2, 4, 6, 8, 10 and 12 weeks after application (WAA).

*Non-replicated, large-plot trials*: In Perlis Plantations Bhd. (PPB) and FELDA, Chuping and Padang Terap, the Airtractor 502, fixed with 10 AU5000 Micronair, applied trinexapac-ethyl at 250 g/ha to 9 to 10 month-old cane on 1 November, 1995. The aircraft delivered a spray volume of 30 L/ha at 176 km/h about 3-4 m above the crop. The plot size of both treated and untreated check was 2 ha in PPB (var. TC1, TC4 and TC6) and FELDA (TC 4 and TC 5). In Padang Terap, the plot size was 5 ha (var. GPT 36). Cane juice was measured for pol (%) at 0, 6 and 9 weeks after application (WAA).

In Lampung, Indonesia, an Ultralite aircraft applied trinexapac-ethyl at 187.5 and 250 g/ha and fluazifop at 125 g a.i./ha to 10-month old cane (var. PSBM 384) on 20 May 1995. The aircraft delivered a water volume of 7 L/ha. The plot size was 2 ha. Cane juice was analysed for pol (%) at 2, 4, 6 and 8 weeks after application (WAA).

## RESULTS AND DISCUSSION

*Replicated, small-plot trials*: Trinexapac-ethyl at 300 g/ha increased pol juice of TC1 and TC4 by more than 1% over the untreated check at 4-10 weeks after treatment (Fig. 1 and 2). At lower rates of 100-200 g/ha, trinexapac-ethyl also increased pol juice of TC 4 by about 1%, but earlier between 2-8 WAA depending on the organic matter levels in the sites (Fig. 7 and 8). These rates of trinexapac-ethyl were superior to glyphosate at 400 to 800 g/ha. TC 4 appeared to be more responsive than TC 1 to trinexapac-ethyl. Pol juice of all treatments passed the 85% purity.

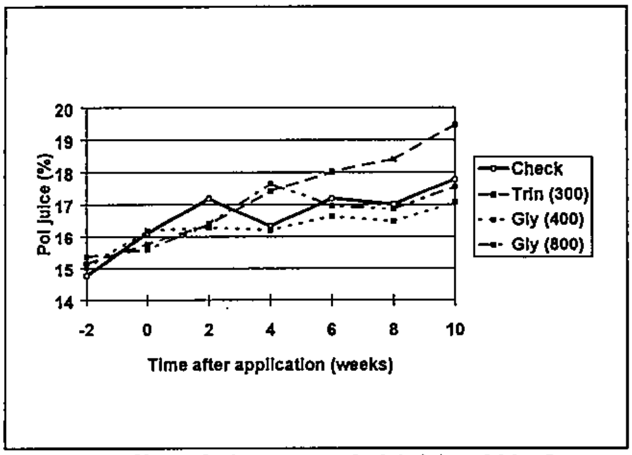


Figure 1. Effect of trinexapac-ethyl (trin) at 300 g/ha and glyphosate (gly) at 400 and 800 g/ha on the pol juice of variety TC 1 in Chuping, Malaysia.

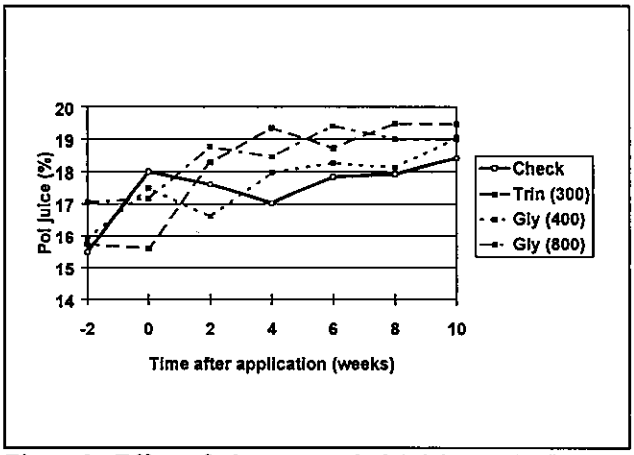


Figure 2. Effect of trinexapac-ethyl (trin) at 300 g/ha and glyphosate (gly) at 400 and 800 g/ha on the pol juice of variety TC 4 in Chuping, Malaysia.

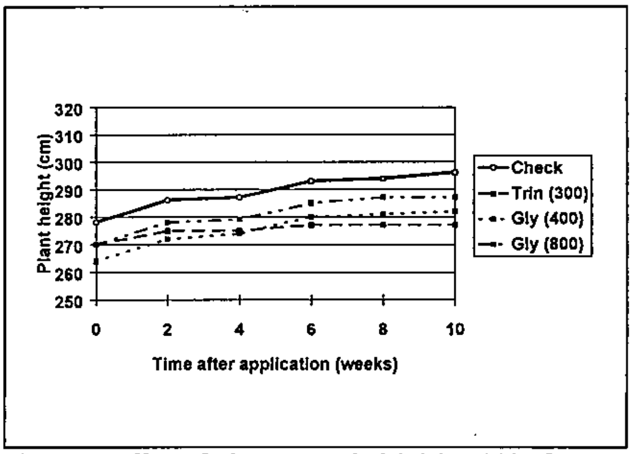


Figure 3. Effect of trinexapac-ethyl (trin) at 300 g/ha and glyphosate (gly) at 400 and 800 g/ha on the height of variety TC 1 in Chuping, Malaysia.

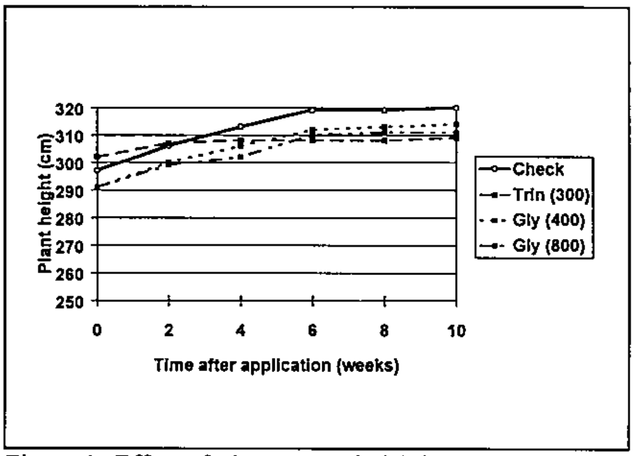


Figure 4. Effect of trinexapac-ethyl (trin) at 300 g/ha and glyphosate (gly) at 400 and 800 g/ha on the height of variety TC 4 in Chuping, Malaysia.

At 300 g/ha, trinexapac-ethyl reduced cane height mainly by shortening the last two to three internodes (Fig. 3 and 4), but had no negative impact on the fiber content (Fig. 5 and 6). The shortening of the last few internodes was expected due to the specific inhibition of the gibberellin, $GA_1$ (1). This may be desirable because the amount of vegetative trash is reduced at harvesting. It also had no side effect on tiller production, plant height and stalk diameter in the following ratoon crop (Table 1). However, glyphosate at 800 g/ha significantly reduced stalk diameter of the following ratoon crop as compared to the untreated check.

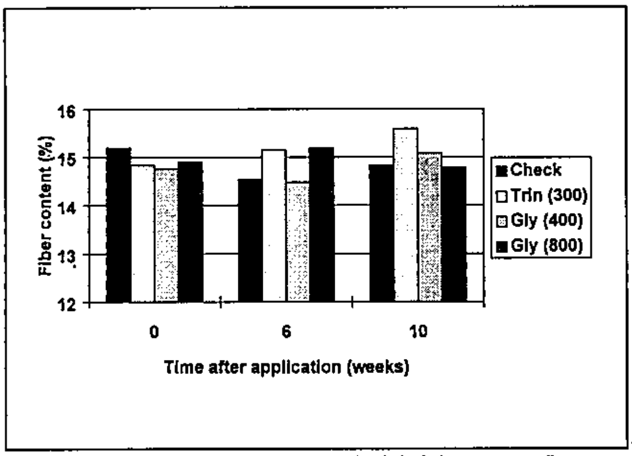


Figure 5. Effect of trinexapac-ethyl (trin) at 300 g/ha and glyphosate (gly) at 400 and 800 g/ha on the fibre content of variety TC 1 in Chuping, Malaysia.

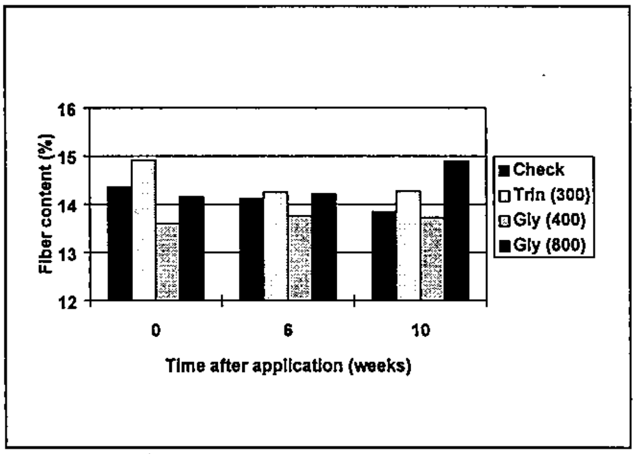


Figure 6. Effect of trinexapac-ethyl (trin) at 300 g/ha and glyphosate (gly) at 400 and 800 g/ha on the fibre content of variety TC 4 in Chuping, Malaysia.

Table 1. Growth of ratoon cane after the previous crop was treated with trinexapac-ethyl and glyphosate in Chuping, Malaysia.

| Variety | Treatment | Rate (g/ha) | Tiller production[1] (no/plot) | Plant height[1] (cm) | Stalk diameter[2] (mm) |
|---|---|---|---|---|---|
| TC 1 | Untreated check | 0 | 283 | 167 | 247 |
| | Trinexapac-ethyl | 300 | 264 | 183 | 237 |
| | Glyphosate | 400 | 287 | 194 | 250 |
| | Glyphosate | 800 | 244 | 165 | 227 |
| TC 4 | Untreated check | 0 | 272 | 159 | 227 |
| | Trinexapac-ethyl | 300 | 286 | 177 | 227 |
| | Glyphosate | 400 | 302 | 176 | 230 |
| | Glyphosate | 800 | 280 | 154 | 217 * |

[1] Analysis of variance indicated no difference among treatments, varieties and the interaction, treatments x varieties.
[2] Analysis of variance indicated differences among treatments (P=0.01), but no difference among varieties and the interaction, treatments x varieties. * LSD showed statistical significance between check and treatment (P=0.05).

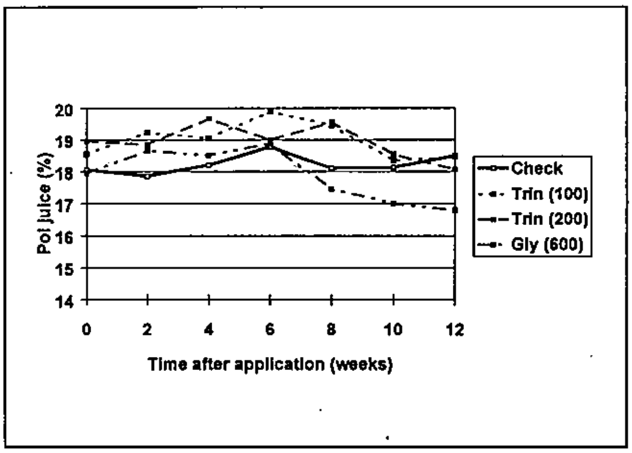


Figure 7. Effect of trinexapac-ethyl (trin) at 100 and 200 g/ha and glyphosate (gly) at 600 g/ha on the pol juice of variety TC 4 grown in site 1 in Chuping, Malaysia.

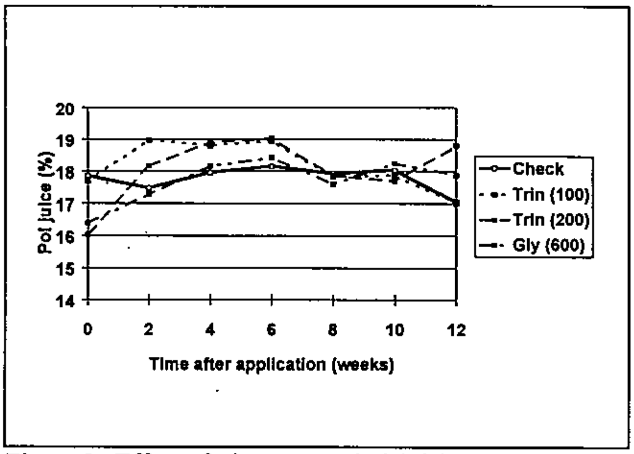


Figure 8. Effect of trinexapac-ethyl (trin) at 100 and 200 g/ha and glyphosate (gly) at 600 g/ha on the pol juice of variety TC 4 grown in site 2 in Chuping, Malaysia.

*Non-replicated, large-plot trials*: In Perlis Plantations and FELDA, Chuping, pol juice in the treated cane increased by 0.69 to 2.93% over the untreated at 6 WAA (Fig. 9). TC4 and TC5 were particularly more responsive to trinexapac-ethyl than other varieties. Trinexapac-ethyl did not reduce plant height, stalk diameter or fiber content of all varieties (data not shown).

In 9 to 10 month old cane in GPT, Padang Terap, pol juice increased by 1.23% at 9 WAA (Fig. 9). Although transient slight yellowing occured, trinexapac-ethyl had no negative impact on cane weight (TCH). In these trials, juice purity all passed the 85% minimum quality. The extra increase in sugar yield was estimated at 0.49 t/ha.

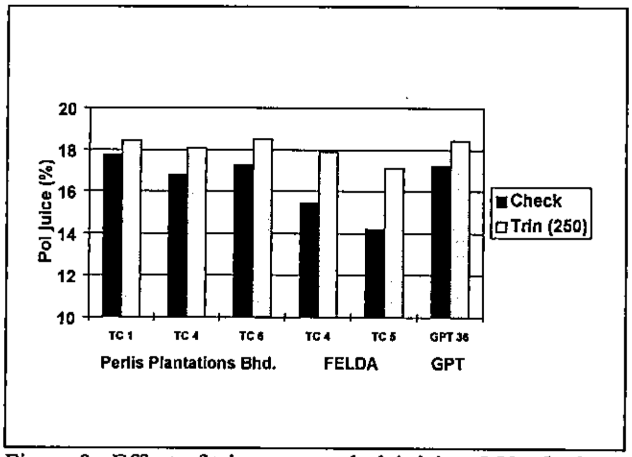


Figure 9. Effect of trinexapac-ethyl (trin) at 250 g/ha by aerial application on the pol juice of sugarcane varieties at 6 WAA in Chuping and 9 WAA in Padang Terap, Malaysia.

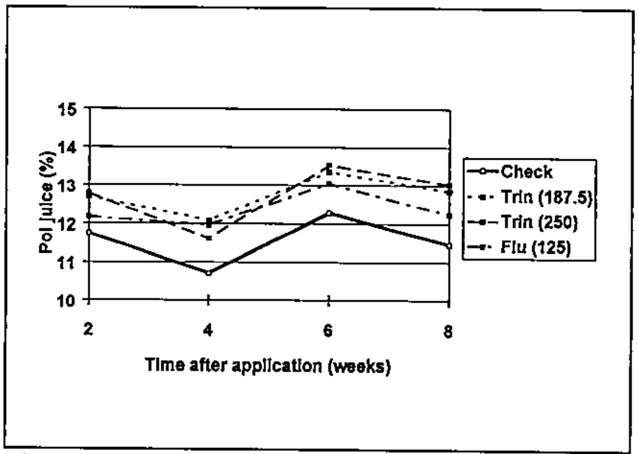


Figure 10. Effect of trinexapac-ethyl (trin) at 187.5 and 250 g/ha and fluazifop (flu) at 125 g/ha on the pol juice of PSBM 384 in Lampung, Indonesia.

In Lampung, Indonesia, trinexapac-ethyl at 187.5 to 250 g/ha increased sugar content by more than 1% pol juice between 4 to 8 WAA although the initial pol juice at 0 WAA was not measured (Fig. 10). It was superior to fluazifop at 125 g/ha, especially at 6 to 8 WAA by 0.49 to 0.78%. On observation, fluazifop produced side-shootings but not trinexapac-ethyl. Based on cane yield and sugar increase, the extractable sugar with trinexapac-ethyl at 250 g/ha was 7'486 t/ha as compared to 5'539 t/ha in the untreated check. In addition, trinexapac-ethyl also improved the quality of juice in terms of brix and purity.

## CONCLUSIONS

In all trials in Malaysia and Indonesia, trinexapac-ethyl at 100 to 300 g/ha consistently increased the sugar content of 9 to 10 month old cane. Depending on the time of harvest and varieties, sugar increase can reach more than 1% pol juice with no negative impact on juice quality, fiber content and cane weight. In short, trinexapac-ethyl increases sugar while extending the harvesting time of sugarcane to allow flexibility in deploying seasonal field labour. It was superior to glyphosate in sugar yield without the risk of damage to the following ratoon crop and with much less risk to neighbouring crops. Trinexapac-ethyl is also more rainfast than glyphosate (unpublished data). From these trials, trinexapac-ethyl should be applied at 200-250 g/ha at 6 to 10 weeks before harvest. It should be used on vigourously growing cane to avoid occasional temporary yellowing under conditions of stress.

## ACKNOWLEDGEMENTS

We thank the Agricultural Research Division of Kilang Gula Felda Perlis Sdn. Bhd., the Agricultural Research Department of Gula Padang Terap Bhd. and PG Bungamayang, Lampung, Indonesia for conducting the field trials. We also thank our colleagues in Basel and U. Hofer who commented on the draft manuscript.

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# ET-75.1, A NEW POST-EMERGENCE BROADLEAF WEED HERBICIDE IN CEREALS

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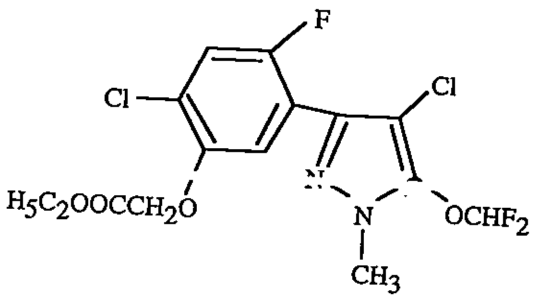
*Summary:* ET-751 is a new selective post-emergence herbicide for use in winter cereals. In extensive field trials in Japan, ET-751 controlled a wide spectrum of annual broad-leaved weeds at as low as 10-20 g a.i./ha with good crop tolerance. The bioefficacy of ET-751 was dependent on growth stages of weeds at application and optimum result was obtained with their younger stages. ET-751 worked quickly and showed high performance within a few weeks after application even under low temperatures. Differences in foliar deposition, absorption and metabolic detoxification were suggested to be relevant factors in the selective action between wheat and weeds.

*Keywords:* ET-751, post-emergence herbicide, selectivity mechanism, cereal herbicide

## INTRODUCTION

ET-751 is a new 3-phenylpyrazole herbicide (Fig. 1) discovered by Nihon Nohyaku Co. Ltd. It is under development worldwide primarily as a post-emergence herbicide for control of broad-leaved weeds in cereals (1). ET-751 inhibits protoporphyrinogen oxidase (protox) and acts rapidly on sensitive weeds at quite low rates (2). In this paper, the results of field trials conducted in Japan are reviewed together with the effects of weed growth stage and low temperatures on the activity of ET-751. Furthermore, the selectivity mechanisms of ET-751 on wheat and a broad-leaved weed, cleavers (*Galium aparine*), are described.




| | |
|---|---|
| Common name | pyraflufen-ethyl (ISO proposed) |
| Chemical name | ethyl 2-chloro-5-(4-chloro-5-difluoromethoxy1 -methylpyrazol-3-yl)-4-fluorophenoxyacetate (IUPAC) |
| Molecular formula | $C_{15}H_{13}C_{12}F_3N_2O_4$ |
| Molecular weight | 413.18 |

Fig. 1: Chemical structure and names of ET-751.

## MATERIALS AND METHODS

*Biological properties*: Since the 1993-1994 growing season, more than 50 field trials, co-ordinated by the Japan Association for Advancement of Phytoregulators, have been carried out to determine the bioefficacy and crop safety of ET-751 in winter cereals at several locations in Japan. ET-751, formulated as a 2% suspension concentrate (SC), was applied post-emergence at rates of 10-20 g/ha in a spray volume of 1000 L/ha. Biomass reductions of broad-leaved weeds as compared to the untreated check were calculated at 20-246 days after treatment (DAT). The crop safety was visually assessed and confirmed by comparing the grain yields to the hand-weeded check. A commercial herbicide, ioxynil-octanoate as a 30% emulsifiable concentrate (EC), was used as a standard in all trials.

ET-751 was applied to different stages of cleavers and common chickweed (*Stellaria media*) infesting winter cereal at a spray volume of 1000 L/ha. Weed control was assessed visually using a 100% scale (0-no effect, 100-complete control) at 21 DAT.

Cleavers were seeded into plastic pots (12 cm in diameter) at intervals of one month and grown outdoors during autumn. When the plants developed to the same growth stage (2-4 whorls), ET-751 was applied to the plants at a spray volume of 1000 L/ha. The mean temperature during 7 DAT on each trial was 16.6°C and 8.6°C, respectively. Weed control was assessed visually using a 100% scale at 7 and 21 DAT.

*Selectivity mechanisms*: Using chloroplasts isolated from wheat and cleavers, the inhibitory activity of ET-751 on protox was determined by measuring accumulated Proto IX with a HPLC equipped with a fluorescence detector.

The third-leaf stage of wheat and the two-whorl stage of cleavers were used for the following experiments. In a foliar deposition study, ET-751 (2.5% EC) was applied to the plants at rates of 3, 10 and 30 g/ha at a spray volume of 600 L/ha. Immediately after application, ET-751 deposited on the plants was removed by rinsing with 30 ml of acetone for 15 and measured with a HPLC equipped with a UV detector. In an absorption study, [*pyrazole*-5-$^{14}$C] ET-751 (5.6 Mbq/mg, 2.5% EC) was applied to the plants at 6 g/ha in the same spray volume. After 1, 8 and 24 h, shoots were weighed and the non-absorbed radioactivity was removed by the same manner. The absorbed radioactivity was extracted with acetone:methanol (1:1). The absorbed and non-absorbed radioactivity were measured by a liquid scintillation counter.

The radiolabeled ET-751 was applied to wheat with 3 leaves and cleavers with 2 whorls. The application rates of ET-751 to wheat and cleavers were 6 and 0.6 g/ha, respectively. After 1, 8 and 24 h, shoots were treated by the same procedure described above, and the absorbed radioactivity was analyzed for metabolites by TLC/autoradiography.

## RESULTS AND DISCUSSION

*Biological properties*: ET-751 at 20 g/ha controlled more than 90% of all annual broad-leaved weeds. The over all efficacy of ET-751 at this rate was superior to the standard herbicide. Among the species, cleavers (Galium *aparine*), *Chenopodium album* and *Lamium* spp. were the most sensitive to ET-751, by which they were controlled more than 98% at 10 g/ha (Table 1). ET-751 caused slight necrotic symptoms temporarily on the developed leaves at application in half the trials. However, the herbicide did not affect the grain yields of winter wheat and barley (Table 2).

The activity of ET-751 decreased depending on the stage of weed growth at the time of application. Such stage dependent activity was more evident on common chickweed, but less on cleavers. This result suggests that ET-751 preferably should be applied up to the fourth-leaf stage of broad-leaved weeds for gaining a wide spectrum of control, while better flexibility was expected on the sensitive weeds such as cleavers (Fig. 2).

The bioefficacy of ET-751 on cleavers at 7 DAT decreased under the low temperature as compared to the high temperature. However, the fluctuation of activity between the two different temperatures was much smaller than that of the standard herbicide. ET-751 controlled more than 90% of cleavers at 21 DAT (Fig. 3). This result indicates that ET-751 could show high activity even when applied under low temperatures.

*Selectivity mechanisms*: As cleavers are one of the most important weeds in cereals and most sensitive to ET-751, it was used in the selectivity mechanism study. The $I_{50}$ values of ET-751 for protox of chloroplasts isolated from wheat and cleavers were 1.6 and 1.2 nM, respectively. This suggests that the intrinsic sensitivity of the target enzyme to ET-751 is similar. Enzyme sensitivity is not relevant to the selectivity in a whole plant.

The deposition of ET-751 on cleavers was 3-5 times higher than that on wheat at each rate of application (Fig. 4). In addition, the amount of radioactivity absorbed by cleavers was about 7 and 13 times as large as that absorbed by wheat at 1 and 24 h after treatment, respectively (Fig. 4). Such large differences of the foliar deposition and absorption of ET-751 contributed to the selective action between the two species.

Three major metabolites of ET-751 were found in both plants. Metabolites I and II were identified as a hydrolysed compound of ET-751 and a N-demethylated compound of metabolite I, respectively. Metabolite III was not characterized well, but appeared to be polar conjugate(s) produced from metabolite II. The inhibitory effect of each metabolite on protox activity in wheat chloroplasts was determined. The $I_{50}$ value of metabolite I was 0.36 nM, which was about one fifth of the amount of ET-751. On the other hand, the $I_{50}$ value of metabolite II was 4.6 nM, which was about 3 times the amount of ET-751. Metabolite III was inactive even at an extremely high concentration (1000 nM). In wheat, metabolite I was rapidly produced and converted to the less active metabolites (II and III). In cleavers, however, the highly active metabolite I increased with time, while the amounts of less active metabolites remained small for the experimental period (Fig. 5). This difference in metabolic detoxification together with the difference of foliar deposition and absorption are the relevant mechanism most likely to explain the selective herbicidal action of ET-751.

Table 1. Activity efficacy of ET-751 on annual broad-leaved weeds. Result was based on field trial in the growing season of 1993/94 – 1995/96 growing seasons in Japan

| Weed species | Growth stage at application (no. of leaves) | Biomass reductions as compared to check (%) | | |
|---|---|---|---|---|
| | | ET-751 at | | ioxynil-octanoate at |
| | | 10g/ha | 20 g/ha | 450 (g/ha) |
| *Capsella bursa-pastoris* | 2 - 4 | 89 | 92 | 96 |
| *Cardamine flexuosa* | 2 - 4 | 89 | 93 | 76 |
| *Cerastium glomeratum* | 1 - 10 | 92 | 97 | 92 |
| *Chenopodium album* | 2 | 98 | 100 | 99 |
| *Galium aparine* | coty. - 6 | 98 | 99 | 97 |
| *Lamium* spp. | 1 - 5 | 100 | 100 | 99 |
| *Polygonum* spp. | coty. - 4 | 85 | 94 | 88 |
| *Senecio vulgaris* | 1 - 3 | 91 | 98 | 86 |
| *Stellaria alsine* | 2 - 5 | 88 | 91 | 98 |
| *Stellatia media* | 1 - 6 | 93 | 99 | 97 |
| Mean | - | 92 | 96 | 93 |

Table 2. Crop safety of winter wheat and barley towards ET-751 field trial results over 1993/94 – 1995/96 growing seasons in Japan

| Crop | Growth stage at application (no of leaves) | ET-751 (20 g/ha) | | ioxynil-octanoate at (450 g/ha) | Yield of hand-weeded plot (t/ha) |
|---|---|---|---|---|---|
| | | Symptom[1] (%) | yield[2] (%) | Yield[2] (%) | |
| Winter wheat (n=30) | 2.5 - 8 | 63 | 100.0 | 98.3 | 4.5 |
| Winter barley (n=28) | 2 – 10 | 50 | 99.3 | 99.1 | 4,8 |

[1]Trials with transient necrotic symptoms
[2] Proportion of hand-weeded plots

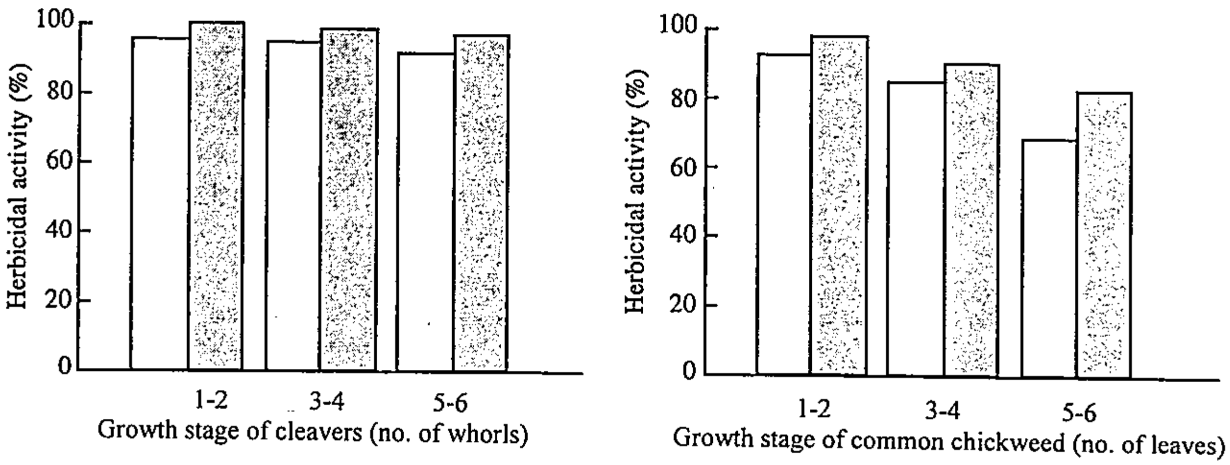



Fig. 2. Herbicidal activity of ET-751 on various leaf stages of cleavers and common chickweed. ET-751 was applied at 10 g/ha □; 20 g/ha □

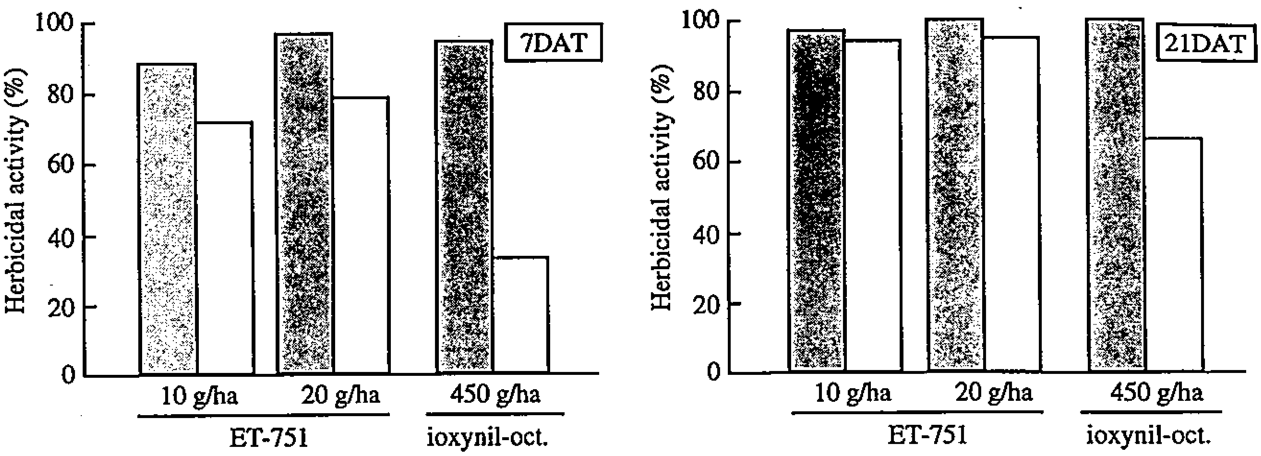



Fig. 3. Herbicidal activity of ET-751 on cleavers under different temperatures after application. Mean temperatures at 7 DAT were 8.6°C, □; 16.6°C, ▨

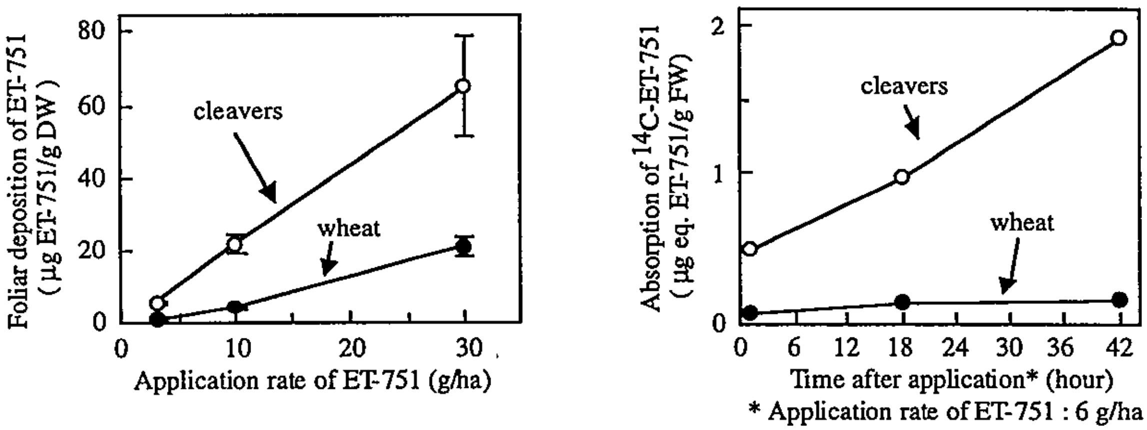



Fig. 4. Foliar deposition (left) and absorption (right) of ET-751 on wheat and cleavers. ET-751 was applied to cleavers and wheat at 6g/ha.

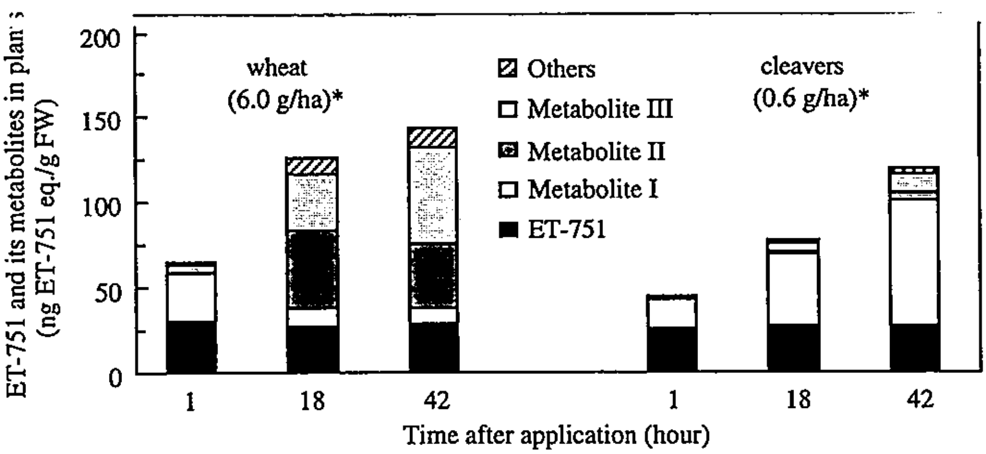



Fig. 5. Metabolism of the absorbed ET-751 in wheat and cleavers. ET-751 was applied to wheat at 6 g/ha and cleavers at 0.6 g/ha.

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# MON 37500: A NEW SELECTIVE HERBICIDE TO CONTROL ANNUAL GRASSES AND BROAD-LEAVED WEEDS IN WHEAT

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*Summary:* MON 37500 (1-(2-ethylsulfonylimidazo [1,2-a] pyridin-3-ylsulfonyl)-3-(4,6-dimethoxypyrimidin-2-yl)urea, is a new selective herbicide, called sulfosulfuron for the control of annual and perennial grasses and annual broad-leaved weeds in wheat. Its mode of action is by inhibition of acetolactate synthase. The product when applied as post-emergence to the crop and weeds in wheat at rates ranging from 20-25 g/ha controlled weeds like *Phalaris minor* (including resistant biotypes), *Melilotus alba, Melilotus indica* and *Sinapsis arvensis.*

*Keywords*: sulfonylurea, *Phalaris*, resistance

## INTRODUCTION

Littleseed canary grass (*Phalaris minor* Retz.) is the most important weed of rice-wheat cropping system in Northern India (1). Almost 5.0 million ha is severely infested with littleseed canary grass. Total dependence on phenylurea herbicides like isoproturon for the control of littleseed canary grass for last 15 years has led to resistance against isoproturon (2). Resistance problem has put a question mark on the sustainability of the rice-wheat system in India.

MON 37500, a new sulfonylurea herbicide (sulfosulfuron in 75% WG), a selective herbicide from Monsanto has shown good efficacy against resistant littleseed canary grass and some common broad-leaved weeds like *Chenopodium album, Melilotus alba, Melilotus indica, Vicia sativa, Sinapsis arvensis* and *Lathyrus species.* This paper presents results from field trials conducted by Monsanto company in fields with resistant littleseed canary fields to study the activity and phytotoxicity of MON 37500 in the states of Punjab and Haryana in India in 1995/96 and 1996/97.

## MATERIALS AND METHODS

In 1995 and 1996, eight replicated trials were conducted with MON 37500 at 20, 25 and 30 g a.i/ha as post-emergence in wheat to study the effective rate of MON 37500 to control little seed canary grass. Treatments were applied at 2 to 4 leaf stage of weed.

In 1996 and 1997, three replicated trials were conducted in Haryana, India. MON 37500 was tested at 20 and 25 g/ha at three different stages of littleseed canary grass (1 to 2, 2 to 4 and 6 to 8 leaves). Separately MON 37500 was also tested at 20, 25, 40 and 50 g/ha at three locations in order to study the phytotoxicity to crop.

In both the years trials, were conducted in fields with resistant littleseed canary grass. The experimental design was a randomized complete block design with three to four replications. The plot size used was 25 to 50 $m^2$. In all the MON 37500 treatments, a surfactant (MON 0818) at 0.5% was tank mixed at the time of spray. Spraying of the herbicides was done with a Solo backpack sprayer fitted with a flat-fan nozzle using 200 to 250 L water/ha. Isoproturon (75 % WP) at 1000 g/ha, metoxuron (80% WP) at 2000 g/ha and diclofop-methyl (28% EC) at 875 g/ha were included as standards. In 1996 and 1997, count of littleseed canary grass count were also recorded before harvest.

In 1995 to 1996, grain yield, phytotoxicity to crop and number of littleseed canary grass, plants/sq.m were recorded at the time of spray and 30 days after spray in each plot using quadrant. In 1996 and 1997, an additional observation at 60 days after spray was also recorded.

## RESULTS AND DISCUSSION

*Phytotoxicity to wheat:* MON 37500 showed good selectivity to wheat and no mortality was recorded. In some cases at 40 and 50 g/ha initial slight growth retardation of the crop was observed, which recovered fully within 20 to 30 days after spray. No yield reduction was observed even at 50 g/ha (Fig.1).

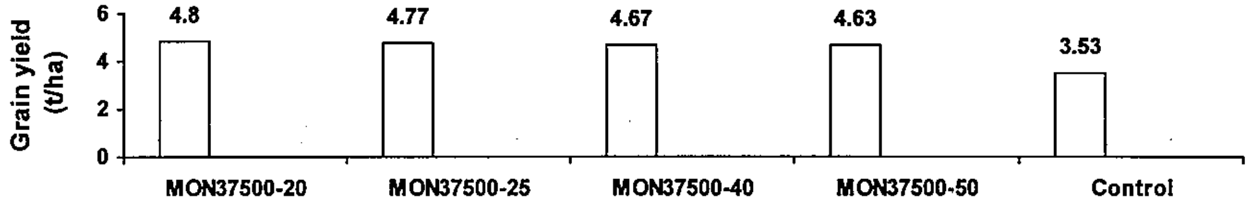


Figure 1. Effect of higher dosage of MON 37500 on grain yield of wheat (1996-97). Mean of three locations.

*Activity of MON 37500 at different rates against littleseed canary grass*: After the application of MON 37500, littleseed canary grass turned dark green in colour and remain severely stunted and finally plants died in 21-30 days after spray. Some of the littleseed canary grass plants remain stunted well below the wheat crop canopy reducing the crop competition. MON at 20-30 g/ha reduced the weed count significantly and increased the grain yield compared with isoproturon (Table 1).

Table 1. Effect on MON 37500 on littleseed canary grass population and grain yield. Mean of eight replicated trials in Punjab, Haryana and U.P. in India (1995-96).

| Herbicides | Rate (g/ha) | Before spray (no./m$^2$) | 30 days after spray (no./m$^2$) | Grain yield |
|---|---|---|---|---|
| Control | 0 | 169 | 254 | 2.5 |
| MON37500 | 15 | 170 | 184 | 3.8 |
| MON37500 | 20 | 167 | 104 | 4.2 |
| MON37500 | 25 | 170 | 52 | 4.4 |
| MON37500 | 30 | 168 | 45 | 4.5 |
| Isoproturon | 1000 | 167 | 199 | 3.2 |
| Metoxuron | 2000 | 168 | 162 | 4.2 |
| Diclofop-methyl | 875 | 166 | 174 | 4.0 |

*Activity of MON 37500 at different rates and time of application against littleseed canary grass*: MON37500 at all the stages of littleseed canary grass recorded excellent control in comparison to isoproturon, diclofop-methyl and metoxuron. MON 37500 demonstrated pre-emergence activity as well, when applied at 1 to 2 leaf stage of littleseed canary grass as it did not allow weeds to emerge. Subsequent flushes of littleseed canary grass were also controlled effectively in MON 37500 treatments (Table 2).

Table 2. Effect on MON 37500 on littleseed canary grass population. Mean of three replicated trials in Haryana, India (1996-97)

| Herbicides | Rate (g/ha) | Application Time* | Plant density | | |
|---|---|---|---|---|---|
| | | | Before spray of MON 3700 (no./m$^2$) | 30 days after spray (no./m$^2$) | 60 days after spray (no./m$^2$) |
| Control | 0 | 0 | 568 | 604 | 600 |
| MON37500 | 20 | 1-2 | 37 | 9 | 11 |
| MON37500 | 25 | 1-2 | 35 | 12 | 11 |
| MON37500 | 20 | 2-4 | 527 | 55 | 40 |
| MON37500 | 25 | 2-4 | 544 | 50 | 40 |
| MON37500 | 20 | 6-8 | 515 | 54 | 46 |
| MON37500 | 25 | 6-8 | 530 | 54 | 49 |
| Metoxuron | 1000 | 2-4 | 509 | 314 | 326 |
| Isoproturon | 2000 | 2-4 | 517 | 452 | 465 |
| Diclofop-methyl | 875 | 2-4 | 512 | 301 | 305 |

*Leaf stage of littleseed canary grass

*Activity of MON 37500 at different rates and time of application against heads of littleseed canary grass and grain yield:* MON 37500 at all the test rates effectively reduced the emergence of heads, which has immense value in reducing the seed bank in the subsequent seasons. Significantly higher grain yield was observed in all the MON 37500 treatments as compared to control and other treatments (Table 3).

Table 3. Effect on littleseed canary grass head count before harvesting and grain yield (t/ha).

| Herbicides | Rate (g/ha) | Application Time* | Head count before harvest (no./m$^2$) | Grain yield (t/ha) |
|---|---|---|---|---|
| Control | 0 | 0 | 307 | 2.8 |
| MON37500 | 20 | 1-2 | 6 | 4.8 |
| MON37500 | 25 | 1-2 | 6 | 4.9 |
| MON37500 | 20 | 2-4 | 4 | 5.0 |
| MON37500 | 25 | 2-4 | 5 | 4.9 |
| MON37500 | 20 | 6-8 | 4 | 4.8 |
| MON37500 | 25 | 6-8 | 5 | 4.8 |
| Metoxuron | 1000 | 2-4 | 137 | 3.7 |
| Isoproturon | 2000 | 2-4 | 194 | 3.4 |
| Diclofop-methyl | 875 | 2-4 | 111 | 3.9 |

*Leaf stage littleseed canary grass

*Bioeffectiveness of MON 37500 at different rates against Melilotus alba*: MON37500 at all the test dosage recorded excellent control of *Melilotus alba* in comparison to isoproturon and metoxuron (Fig 2).

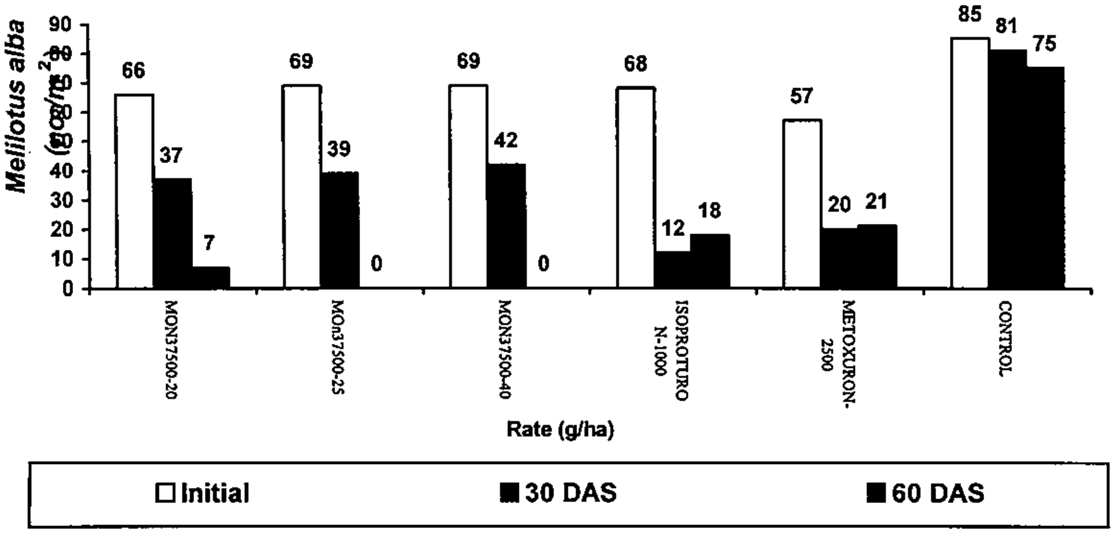


Figure 2. Effect of MON 37500 against *Melilotus alba* when applied at 2 to 4 leaf stage of the weed

## CONCLUSIONS

MON 37500 offers an excellent option to wheat growers to control resistant littleseed canary grass and broad-leaved weeds. It exhibits crop safety to wheat crop and flexibility in time of application.

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# IMAZAPIC - A NEW HERBICIDE FOR CONTROL OF SUMMER FALLOW WEEDS IN THE NORTHERN AUSTRALIAN WHEATBELT

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*Summary:* The compound imazapic was evaluated from 1988 to 1995 in experiments for pre-emergence control of weeds emerging in fallow during summer months. Imazapic applied at rates between 36 and 50 g active constituent per hectare (g/ha) either as a pre-emergence treatment alone, or a post-emergence treatment with a knockdown herbicide, provided six to twelve weeks control of a range of grass and broad-leaved weeds in fallow. Grass weeds included liverseed grass (*Urochloa panicoides*), barnyard grass (*Echinochloa colona*), stink grass (*Eragrostis cilianensis*), button grass (*Dactyloctenium radulans*) and blowaway grass (*Panicum decompositum*). Broad-leaved weeds controlled included yellowvine (*Tribulus terrestris*), pigweed (*Portulaca oleracea*), boggabri weed (*Amaranthus mitchellii*), dwarf amaranth (*Amaranthus macrocarpus*), peachvine (*Ipomoea lonchophylla*) and mintweed (*Salvia reflexa*). Imazapic in the rate range 36 to 50 g/ha provided reliable control of the range of fallow weeds investigated, with the higher rates effective over a longer period of time (of up to twelve weeks), without significant risk of follow crop damage or yield depression.

*Keywords:* imidazolinone, imazapic, fallow weeds.

## INTRODUCTION

Control of weeds in the five month of summer fallow between successive crops is essential to maximise soil moisture conservation in the dryland cropping regions of north-eastern Australia. The high probability of moisture stress resulting from scant rainfall during the autumn sowing period is a major constraint to crop yield in this region (1). In recent years, conservation tillage practices, and in particular zero tillage, have greatly improved soil water conservation through reduced evaporation and retention of crop residues on the soil surface, aiding more efficient holding and infiltration of incident rainfall. Winter crops grown in continuous rotation have significantly increased the importance of grass weeds such as *E. colona* ,*U. panicoides* and *E. cilianensis*. Such weeds are difficult to control in summer fallow where successive germination can occur over several months. In addition, moisture stress in fallow weeds can significantly reduce the effectiveness of knockdown herbicides.

The prospect of unreliable control of summer fallow grass weeds has restricted the adoption of zero-tillage practices in many districts where grasses are a major problem. Herbicide treatment costs are often high, requiring two to three applications between November and March. Prior to imazapic there were no compounds available for the reliable control of successive germination of weeds in fallow which do not threaten follow crop safety. Imazapic ((±)-2-(-4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-5-methylnicotinic acid, [IUPAC]), is an imidazolinone herbicide (trade name FLAME*), developed by American Cyanamid Company. Field evaluation has demonstrated that imazapic provides a high level of short to mid-term residual control of a range of key grasses and broad-leaved weeds in fallow under Australian conditions. This paper describes the performance of imazapic against fallow weeds and subsequent re-cropping to wheat, barley and chickpeas.

## MATERIALS AND METHODS

Field trials were conducted at twenty six locations in north-eastern Australia from 1988 to 1995, with the purpose of pursuing regulatory approval for commercial use. Treatments were applied to replicated plots using calibrated trial-plot sprayers. Both 24% aqueous concentrate and 70% water dispersable granule formulations were tested under zero tillage and minimum tillage cultivation practices. Treatments were applied between November and February (most between November and December). Where emerged weeds were present at application, a combination of imazapic and glyphosate was applied to ensure effective knockdown.

The composition of weed populations varied between sites. In most cases grass weeds were the more prevalent species, while in others there was a mixture of grasses and broad-leaved weeds.

Pre-emergence grass and broad-leaved weed control was assessed by estimating the percentage weed cover, where a value of 2% or less ground cover was considered commercially acceptable.

Re-crop phytotoxicity was assessed subjectively as an estimate of percent growth reduction. In some experiments crop establishment was recorded, while in others a subjective estimate of percentage stand reduction was recorded. Yields were calculated following sub-plot harvesting with a Hege small-plot harvester.

In all experiments, knockdown treatments (glyphosate) were applied to the plots once the effectiveness of the pre-emergence treatments became unacceptable, in line with current fallow management practice. Cultivation following application of treatments was not carried out prior to re-cropping in the majority of the experiments reported here.

## RESULTS AND DISCUSSION

*Pre-emergence control of grass weeds*: Pre-emergence treatment with imazapic applied alone at 36 g ai/ha provided commercially acceptable control of *U. panicoides, E. colona* and *E. cilianensis* for six to twelve weeks after treatment in 10 of 13, 11 of 13, and 4 of 5 experiments, respectively. At 50 g/ha, commercially acceptable control of the same grass species was achieved in 12 of 17, 16 of 17 and 6 of 6 experiments, respectively (Fig 1). Control of *P. decompositum* was achieved in all trials where it was present. Control of *D. radulans* was assessed in three experiments; unsatisfactory control in one was due to the survival of established plants present at the time of treatment.

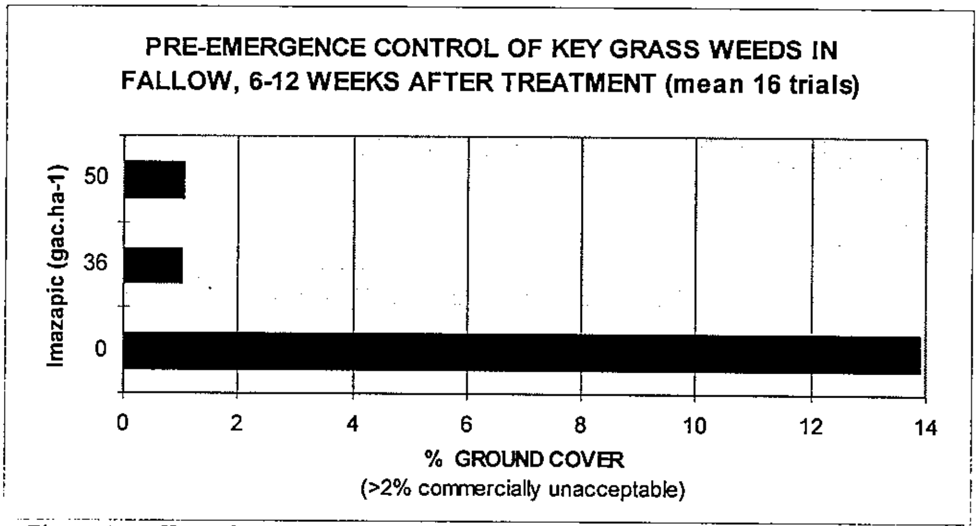


Figure 1. Effect of pre-emergence applications of imazapic on grasses in summer fallow.

Weed escapes were often the result of the failure of the knockdown component of the tank-mix to control emerged weeds, or where the application was timed before the completion of a sequence of weed germination (which continue for some time after a rainfall event) even where the top 1 cm of soil has dried A feature of the results was the reliability of weed control when imazapic was applied pre-emergence to bare, dry soils or to standing crop residues. Pre-emergence activity appeared to be unaffected, even where activating rainfall did not occur for some weeks following a pre-emergence treatment to dry soil.

*Pre-emergence control of broad-leaved weeds*: In general, broad-leaved weeds did not make up the dominant component of the weed spectrum in these fallow situations, and were of minor importance compared with grasses. Imazapic gave control of such commonly occurring species as *T. terrestris, P. oleracea, S. reflexa, I. lonchophylla* and *Amaranthus* spp. (Fig 2). Common sowthistle (*Sonchus oleraceus*), camel melon (*Citrullus lanatus* var. *lanatus)* were not well controlled by imazapic.

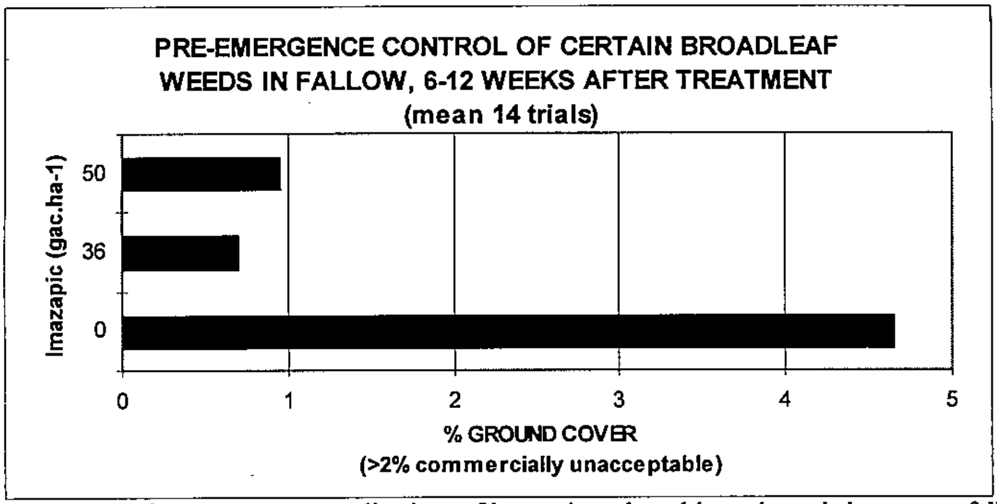


Figure 2. Effect of pre-emergence applications of imazapic on broad-leaved weeds in summer fallow.

*Imazapic in combination with glyphosate*: Combinations of 25 to 100 g/ha imazapic with glyphosate generally did not improve knockdown weed control over glyphosate applied alone. As imazapic at these dose rates gives pre-emergence weed control only, glyphosate is a necessary tank-mix partner for situations where weeds have emerged prior to imazapic application.

*Crop safety*: In spite of some transient crop injury noted at the vegetative growth stage of winter crops in 2 of 13 experiments, yields of wheat and barley were not reduced following fallow application of imazapic at either 37 or 50 g/ha, compared to fallow maintained with knockdown herbicides (Fig 3).

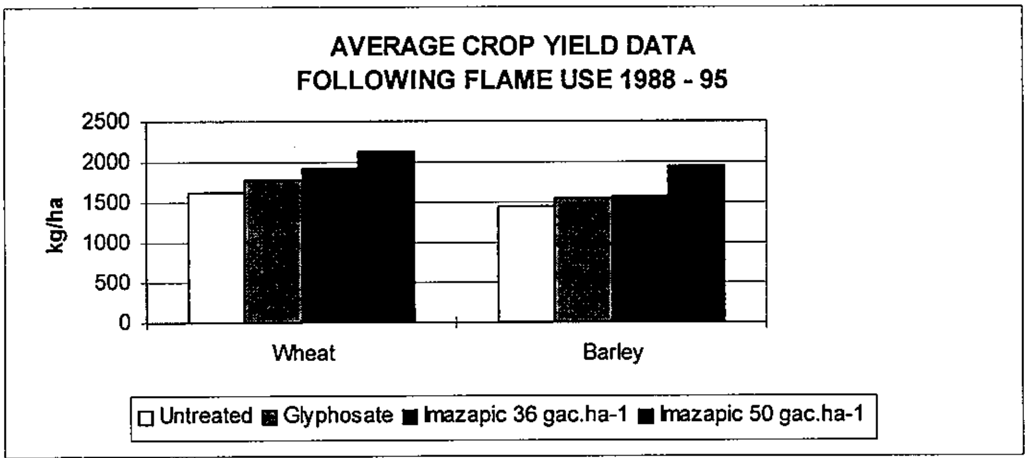


Figure 3. Effect of fallow applications of imazapic and glyphosate on re-crop yields.

Fallow experiments were re-cropped to winter crops except in three instances where failure of winter rains did not provide a planting opportunity. In applications of 100 g/ha, twice the proposed use rate, unacceptable crop phytotoxicity was noted in some re-cropping experiments. Severe growth reduction was noted in 6 of 13 and 5 of 9 experiments where wheat and barley were re-cropped, respectively. In these trials crop injury was more apparent where rainfall during the fallow period was less than 200 mm, and where little crop stubble was present to retain soil moisture. The commercially acceptable phytotoxicity observed in cereal crops at the maximum use rate proposed did not affect yield

The primary path of degradation of the imidazolinone herbicides in soils is by microbial breakdown (2), and so phytoxicity is highly dependant upon rainfall and consequent soil microbial activity during the fallow period. Carryover and therefore phytotoxicity appeared to be related initially to low rainfall in the fallow and was enhanced by continued low in-crop rainfall.

The impact of overspray (double rate application) in the commercial situation is unlikely to be substantial considering the relatively small area affected following boom overlap.

## CONCLUSIONS

Imazapic in the rate range 36 to 50 g/ha provided reliable control of the range of fallow weeds investigated. The higher rates were effective over a longer period of time, up to twelve weeks, with minimal risk of follow-crop damage or yield depression. Registration, based on these trial results, was granted for commercial imazapic use in northern Australia in November, 1996. Up to the time of writing this paper, some 25,000 ha of fallow had received commercial applications. Field reports indicate the compound continued achieving effective control of target weeds in fallow for a period of up to twelve weeks in 1996-97 fallows in northern Australia.

## ACKNOWLEDGEMENTS

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# ADSORPTION, DESORPTION, MOBILITY AND DEGRADATION OF THREE COMMONLY USED HERBICIDES IN MALAYSIAN AGRICULTURAL SOILS

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*Summary:* High Freundlich adsorption distribution coefficients ($K_{ads(f)}$) were observed for paraquat (28.7 and 1419) and glyphosate (83.8 and 417) and lower values for 2,4-D (0.57 and 5.26) in a sandy loam and a muck soil, respectively. Leaching of 2,4-D was evident. Short half-lives were observed for 2,4-D in aerobic (3.4 days) and anaerobic (9.3 days) muck soils while longer half-lives were found for glyphosate (19.2 days) and 2,4-D (35.9 days) in the sandy loam. Long half-lives were observed for paraquat (1.4-7.2 years).

*Keywords:* 2,4-D, paraquat, glyphosate, soil residues, herbicide residues

## INTRODUCTION

Glyphosate, paraquat and 2,4-D are three commonly used herbicides in Malaysian agriculture. These herbicides are used for the control of a wide range of broad-leaved weeds and grasses in plantation crops such as rubber, oil palm and cocoa. Usage of glyphosate has gained momentum in recent years as a result of a reduction in the price of the herbicide after patent expiry. The popularity of 2,4-D for the control of broadleaf weeds in the rice ecosystem is reflected in the estimated annual usage valued at RM 4 million (2). Studies on the adsorption, desorption, mobility and degradation of herbicides in Malaysian soils are limited (1, 2, 3). Data on these studies provide comprehensive information on the environmental fate of agrochemicals in Malaysian soils.

## MATERIALS AND METHODS

*Adsorption-desorption*: Soils, collected from a rice-growing area in Tanjong Karang (Selangor) and a vegetable-growing area in the Cameron Highlands (Pahang) were air-dried, sieved and classified as muck and sandy loam respectively.

Pesticide solutions were prepared using non-labelled materials and $^{14}C$-labelled 2,4-D, glyphosate and paraquat. Soil (2 g) was shaken with the pesticide solution (10 ml) in an orbital shaker for 4 h, the time to achieve equilibrium concentration. The contents were centrifuged and the supernatant (1 ml) was radioassayed. Desorption studies were performed using 1.0 mg/L pesticide solutions.

*Mobility:* Muck (120 g) and sandy loam (165 g) soils were placed in a glass column comprising two segments (15 cm length x 2.5 cm diameter) held together using clamps to provide a total depth of 25 cm. Radiolabelled pesticides, augmented with non-labelled materials, were introduced into the column. Distilled water was then passed through the column to simulate 200 mm rainfall. The flow rate was adjusted such that the volume of water used was eluted within 48 h. The leachate was collected at the end of the two-day period. An aliquot (5 ml) of the leachate was radioassayed. The soil from the top 10 cm, middle 10 cm and bottom 5 cm of the glass segments was air dried, homogenised and three sub-samples from each soil layer were combusted and radioassayed. The CALF model as modified by Walker (10), Walker and Welch (12) and given the name VARLEACH by Walker and Hollins (11), was used to predict the leaching of the pesticides.

*Degradation:* The soil (100 g) was placed in a biometer flask and the experiment conducted in a controlled environment chamber with the temperature maintained at 30°C (± 1°C), 80% (± 2%) humidity and in total darkness. Sterilised soils were used as controls. Radiolabelled pesticides, augmented with non-labelled analytical standard materials, were introduced in the biometer flask based on the field application rates used in Malaysia. Sampling was conducted at various intervals by taking the three replicate flasks. An aliquot of the NaOH solution was radioassayed. The soils (100 g) sampled at various intervals were extracted and examined by TLC. An aliquot of the soil extracts was radioassayed. After solvent extraction, the soil was air-dried and an aliquot (0.3 g) oxidised to determine the amount of non-extractable residues. In view of the slow degradation of paraquat in soils, extraction of the aqueous phase and soils was not conducted.

The method of Smith and Aubin (8) was used for the extraction and identification of 2,4-D and its metabolites 2,4-dichlorophenol and 2,4-dichloroanisole. The method of Rueppel (7) was used for the analysis of glyphosate and its metabolites in soils and water.

## RESULTS AND DISCUSSION

*Adsorption-desorption:* Adsorption of 2,4-D, paraquat and glyphosate to both sandy loam and muck soils was found to best fit a Freundlich adsorption isotherm. Adsorption (Kads), desorption (Kdes) and organic carbon (Koc) distribution coefficients are given in Tables 1 and 2. High Kads values were observed for paraquat and glyphosate, indicating high adsorption of both herbicides to the soils. Adsorption was higher in the muck soil. Significant desorption of 2,4-D occurred from both soils. Desorption of paraquat from the soils was not evident. Desorption of glyphosate to both soils was evident, but was significantly higher ($P = 0.01$) in the sandy loam.

Table 1. Adsorption, desorption and organic carbon distribution coefficients of pesticides in the sandy loam soil

| Parameter | Herbicide | | |
|---|---|---|---|
| | 2,4-D | Paraquat | Glyphosate |
| Kads(l) (L/kg) | 0.49±0.07 | 56.4±0.71 | 133±5.2 |
| Kads(f) (L/kg) | 0.57±0.69 | 28.7±1.2 | 83.8±1.4 |
| 1/n | 0.96±0.18 | 0.60±0.05 | 0.85±0.08 |
| Koc (L/kg) | 43.9±53.1 | - | - |
| Kdes1 (L/kg) | 2.57±0.34 | 1304±210 | 103±4.3 |
| Kdes2 (L/kg) | 5.34±0.47 | NA | 200±8.1 |
| Kdes3 (L/kg) | 10.3±1.0 | NA | 251±32 |
| Kdes4 (L/kg) | 16.9±1.4 | NA | 251±32 |
| $r^2$ | 0.92 | 0.96 | 0.98 |

NA Not available as desorption did not occur

Table 2. Adsorption, desorption and organic carbon distribution coefficients of pesticides in the muck soil.

| Parameter | Herbicide | | |
|---|---|---|---|
| | 2,4-D | Paraquat | Glyphosate |
| Kads(l) (L/kg) | 6.95±1.72 | 1693±145 | 1188±252 |
| Kads(f) (L/kg) | 5.26±1.27 | 1419±2.2 | 417±1.4 |
| 1/n | 0.77±0.13 | 1.01±0.13 | 0.78±0.06 |
| Koc (L/kg) | 17.3±4.2 | - | - |
| Kdes1 (L/kg) | 28.7±3.8 | NA | 971±200 |
| Kdes2 (L/kg) | 48.5±4.0 | NA | 4720±5.9 |
| Kdes3 (L/kg) | 51.9±11.1 | NA | 4716±6.2 |
| Kdes4 (L/kg) | 44.6±4.0 | NA | NA |
| $r^2$ | 0.93 | 0.96 | 0.99 |

NA Not available as desorption did not occur

Table 3. Pesticide leaching in soils under a simulated 200 mm rainfall

| Pesticide | Radioactivity (% applied) | | | |
|---|---|---|---|---|
| | Leachate | | Soil | |
| | Sandy loam | Muck | Sandy loam | Muck |
| 2,4-D | 4.58±1.60 | 0.23±0.07 | 80.87± 8.00 | 76.07± 9.54 |
| Paraquat | 0.037±0.52 | 0.006±0.014 | 53.13± 8.51 | 77.01± 6.60 |
| Glyphosate | 0.073±0.013 | 0.044±0.001 | 69.1± 12.9 | 69.11± 8.44 |

Table 4. First-order rate constants (k), half-lives ($t_{1/2}$) with 95% confidence limits (*) and determination coefficients ($r^2$) in soils

| Soil | Pesticide | $r^2$ | k (days$^{-1}$) | $t_{1/2}$ (days) | $t_{1/2}$ 95% c.l.* |
|---|---|---|---|---|---|
| Aerobic sand | 2,4-D | 0.76 | 0.019 | 35.9 | 29.1 - 21.6 |
| | Paraquat | 0.92 | 0.00074 | 941.3 | 839.2 - 1072 |
| | Glyphosate | 0.93 | 0.036 | 19.2 | 17.3 - 21.6 |
| Aerobic muck | 2,4-D | 0.89 | 0.21 | 3.4 | 2.8 - 4.2 |
| | Paraquat | 0.96 | 0.0014 | 499.2 | 405.1 - 650.9 |
| | Glyphosate | 0.86 | 0.0022 | 309.7 | 266.1 - 370.3 |
| Anaerobic muck | 2,4-D | 0.73 | 0.075 | 9.3 | 7.2 - 13.0 |
| | Paraquat | 0.76 | 0.00024 | 2614 | 2289 - 3652 |
| | Glyphosate | 0.52 | N/A | N/A | N/A |

* c.l. Confidence limits N/A Not available

*Mobility:* Leaching of [$^{14}$C]2,4-D in the sandy loam and muck soil columns amounted to 4.58% and 0.23% respectively (Table 3), corresponding with the results of several studies, indicating the mobility of 2,4-D in sandy and low organic soils (4, 5). Paraquat leaching was not evident in either sandy loam or muck soil columns. Little mobility of glyphosate was observed in the muck soil column, similar to that reported by Sprangle (6, 8). A slightly greater mobility was observed in the sandy loam, suggesting possible leaching of glyphosate to lower layers which may have limited biological activity. Comparable results in the leaching of 2,4-D were observed between laboratory studies and a CALF model prediction.

*Degradation:* In the degradation process of 2,4-D, half-lives of 35.9, 3.4 and 9.3 days were estimated from the first-order kinetics in aerobic sandy loam, aerobic muck and anaerobic muck, respectively (Table 4). The corresponding values for paraquat were 2.6, 1.4 and 7.2 years, respectively. Half-lives for glyphosate of 19.2 and 309.7 days (10.3 months) were obtained for sandy loam and aerobic muck soils, respectively. A half-life for the anaerobic muck could not be determined as a first-order degradation kinetic was not observed for the soil ($r^2$=0.52). The rapid degradation of glyphosate in the sandy loam was attributable to the relatively lower degree of binding to the soil.

The formation of the degradation products of 2,4-D, 2,4-dichlorophenol and 2,4-dichloroanisole was not evident. Amino-methylphosphonic acid was found as the sole metabolite of glyphosate in the soil extracts from the sandy loam, an observation similar to previous studies (6, 7).

It was noted that the results of the laboratory studies on the degradation of 2,4-D, paraquat and glyphosate in the Malaysian soils showed little difference from the results reported in soils from other parts of the world.

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# MOBILITY OF FOUR SULFONYLUREA HERBICIDES IN SOME NEW ZEALAND AND MALAYSIAN SOILS

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*Summary*: Laboratory and glasshouse experiments compared the mobility of four sulfonylurea herbicides in 300 mm polyvinyl chloride columns filled with one of four Malaysian or four New Zealand soils. Herbicide activity was measured through bioassays with mustard (*Sinapis alba*). The distance which a herbicide moved within the soil increased with its water solubility and the amount of water added to the column. Mobility of all herbicides was higher in sandy soils and in soils with high pH levels. Overall, bensulfuron showed very low mobility in all soils while metsulfuron was generally the most mobile. Azimsulfuron and chlorimuron were slightly less mobile than metsulfuron.

*Keywords*: sulfonylurea herbicides, mobility, leaching

## INTRODUCTION

The sulfonylureas represent a major class of novel herbicides which have been increasingly used since the 1980's for controlling a wide spectrum of broadleaf and grass weeds. Various members of the group are registered for use in cereals, rice, soybeans, oilseed rape, rangeland, forests and for total vegetation control (2, 3, 9). Safeners are also being experimented with to extend the crops in which these herbicides can be used. The broad spectrum and reliability of weed control, low dose rates, ease of handling, and the favourable toxicological profiles of these compounds have contributed to the rapid increase in their use (1, 2, 3). Because these herbicides have high activity, their movement, persistence and length of residual activity in the soil are particularly important considerations with regard to their potential damage to crops and environmental pollution. This is especially so because many broad-leaved crops, including many vegetables, are sensitive to very low concentrations in soil (6, 13).

The persistence of sulfonylurea herbicides and their mobility down the soil profile is dependent on various environmental and soil factors which determine adsorption and degradation in soil (3, 11). Although their soil mobility has been the topic of many laboratory and field studies, most studies have concentrated on chlorsulfuron. Laboratory studies have employed different methods to measure the movement in soil, but the most satisfactory approach is one which best approximates actual field conditions and is reproducible. In general, studies based on the mobility of herbicides in soil columns have produced the best results and this approach allows for variations in the amount and rate of water addition over different time periods. This is important because the amount of water entering the soil as a function of time is the most significant factor affecting water and herbicide movement in soil (8, 10, 12).

The herbicide bensulfuron is among the early generation sulfonylureas developed for pre-emergence or early post-emergence control of broad-leaved weeds and sedges in direct-seeded and transplanted rice (2, 3). Azimsulfuron is a new pre-emergence sulfonylurea intended to supersede bensulfuron as it gives superior control of *Echinochloa* spp. (4). Metsulfuron is used in many countries for weed control in cereals as well as for controlling many woody weeds (1, 3). Chlorimuron has been primarily used for post-emergence control of broad-leaved weeds in soybeans (3) and is registered in New Zealand for selective weed control in lucerne. All these herbicides are largely anionic in soils of normal agricultural pH (6.0 and above), and are consequently only weakly adsorbed (1, 3, 14). Therefore, they have the potential to leach, especially in certain soils and under conditions of high rainfall. Although some information is available on the soil mobility of these herbicides, no comparative studies have been made to assess their mobility patterns in tropical and temperate soils. The objective of the present study was to determine the mobility through leaching in soil columns, of four sulfonylurea herbicides in several New Zealand and Malaysian soils with different physico-chemical characteristics.

## MATERIALS AND METHODS

These experiments were performed in 300 mm long columns made from polyvinyl chloride (PVC) pipe of 100 mm inside diameter (7). Each column was cut longitudinally to make a 40 mm wide gap which was covered with clear acetate sheet for the first part of the experiments. A perforated PVC cap was attached to the bottom of the column before filling with soil.

*Experiment 1*: This included eight soil types, four from New Zealand and four from Malaysia. Some physical and chemical characteristics of these soils are listed in Table 1. Bulk soils were collected from the top 100 mm in the field, thoroughly mixed and screened through a 4 mm sieve. They were then gently packed in the field moist condition into the columns to a height of 260 mm. After allowing the column to settle for 24 h, a further 20 mm thick layer of soil pre-mixed with the required rate of herbicide was placed on top of the column, leaving a gap of 20 mm for adding the water. Two nylon string markers were placed between the treated layer and the untreated soil in the column to act as a reference point for measuring herbicide movement at the end of the experiment. The herbicides investigated were azimsulfuron, bensulfuron, chlorimuron and metsulfuron at 30, 60, 30 and 20 g ai/ha respectively. The amount of herbicide applied to the treated soil layer was calculated from the soil surface area at the top of the column. The required amount of herbicide was applied in 100 ml water/kg of soil and was thoroughly mixed with the soil in a polythene bag before being placed in the column. The soil in the column was topped with a filter paper and 5 mm of washed sand to allow an evenly distributed water load to the treated soil. The columns were placed on a bench in the laboratory and water was added to the top of each soil column with a pipette in 20 ml aliquots over a 2-3 day period until it had uniformly reached the bottom of soil column (400 to 540 ml depending on the soil). Untreated controls were also maintained for each soil type.

Table 1: Some physico-chemical characteristics of the soils used in the study.

| Soil type[1] | Sand (%) | Silt (%) | Clay (%) | Organic C (%) | pH |
|---|---|---|---|---|---|
| Bertam | 55.9 | 18.6 | 25.6 | 1.63 | 4.95 |
| Bungor | 33.6 | 22.5 | 43.9 | 1.39 | 4.45 |
| Malacca | 44.8 | 28.8 | 26.5 | 0.91 | 4.70 |
| Serdang | 53.7 | 25.8 | 20.4 | 1.50 | 6.10 |
| Hamilton | 55.0 | 18.0 | 28.0 | 3.10 | 5.20 |
| Horotiu | 58.0 | 27.0 | 15.0 | 6.20 | 5.80 |
| Te Kauwhata | 34.0 | 23.0 | 43.0 | 2.40 | 7.30 |
| Whakatane | 89.0 | 10.0 | 2.0 | 5.70 | 5.40 |

[1] The first four soils are from Malaysia and the last four are New Zealand soils.

Upon completion of the watering regime, the columns were left to equilibrate for 24 h, after which the filter paper and sand were removed. These columns were filled with vermiculite and then laid on their side and opened longitudinally by removing the acetate sheet. The soil was scraped to level it with the side walls, starting from the bottom to avoid contamination, in preparation for bioassays in the glasshouse. Seeds of the bioassay species, mustard (*Sinapis alba*), were sown in duplicate at 20 mm intervals along the length of the column. The columns were then placed in a heated glasshouse with day temperatures of 20-24°C and night temperature down to 16°C. No supplementary light was provided. This experiment was conducted in autumn (April-May) 1996 and the soils were kept moist by mist watering daily. Four replicates were allocated to each treatment for each soil type and the columns were arranged in a completely randomised design. After 3 weeks of growth in the glasshouse, plants were assessed for herbicide damage and then harvested in pairs at each increment for fresh weight determinations. The distance that the herbicide leached was determined as the distance from the string markers to the first plants that had a fresh weight of within 85% of equivalent plants in the untreated columns. The data were subjected to analysis of variance to separate the means.

*Experiment 2*: This investigated how the movement of herbicide was affected by different amounts of water applied to the column. It included the same four herbicides, each at two application rates, and two of the soil types from New Zealand (Table 3). The amount of water added to the column was (i) to 75% of the length of the column, (ii) to 100% length of the column, and (iii) to 150% length of the column, i.e. 1.5 times the water required for (ii); the excess water being allowed to leach out of the bottom of column. This experiment was conducted in the spring (October - November) 1996, with day temperatures of 24 - 30°C and night temperature down to a minimum of 16°C. All other aspects of the study were the same as described above for Experiment 1.

## RESULTS AND DISCUSSION

The most common visual effect of all the herbicides on mustard was stunting, usually caused by a reduction in the number of lobes on the leaves. This was followed by chlorosis and then necrosis of the growing point and young leaves leading to severe reduction in both shoot and root growth. At the rates used in these experiments, the herbicide damage was usually very distinct, with the plants in the contaminated soil not growing past the cotyledon stage. In the columns, the presence of herbicide in the soil was very obvious as the bioassay plants went from practically no growth (i.e. no true leaves) to unaffected growth in a distance of 20-40 mm.

The average distance that each herbicide moved down the soil profile within each column (based on visual observations and fresh weight of plants) is given in Table 2. There were only small variations between the four replicates, demonstrating high reproducibility of results with this technique. In general, the mobility of four herbicides was closely related to the water solubility of the compound. The water solubility at pH 5 is 2.9, 11.0, 72.3 and approx. 800 ppm for bensulfuron, chlorimuron, azimsulfuron and metsulfuron, respectively. Thus metsulfuron was generally the most mobile compound in all the soils and bensulfuron exhibited the least mobility in both experiments. Azimsulfuron and chlorimuron showed intermediate mobility in the soils included in this study. Using bioassay techniques, the extent of mobility of a herbicide in soil columns has previously been found to be closely related to its biological activity through the soil (11). Both metsulfuron and azimsulfuron have been reported to be among the more persistent sulfonylurea compounds and to have a high level of activity through the soil (4, 5, 14), which could help explain why they were detected so far down the column.

Table 2. Comparative mobility of four sulfonylurea herbicides in eight different soils packed in 300 mm PVC columns (Experiment 1).

| Soil | Distance leached (mm) | | | |
|---|---|---|---|---|
| | Azimsulfuron | Bensulfuron | Chlorimuron | Metsulfuron |
| Bertam | 40 | 20 | 60 | 70 |
| Bungor | 45 | 20 | 50 | 75 |
| Malacca | 30 | 40 | 55 | 80 |
| Serdang | 50 | 40 | 60 | 90 |
| Hamilton | 100 | 10 | 70 | 100 |
| Horotiu | 75 | 10 | 55 | 80 |
| Te Kauwhata | 170 | 100 | 170 | 175 |
| Whakatane | 160 | 100 | 140 | 160 |
| l.s.d. (P=0.05) | 18 | 16 | 21 | 25 |

All the four herbicides investigated here exhibited the highest mobility in the Te Kauwhata and Whakatane soils, both from New Zealand (Table 2). The Te Kauwhata soil had the highest pH and was the only non-acidic one of all the soils studied (Table 1). Many researchers have shown greater phytotoxicity and mobility of sulfonylurea herbicides with increasing soil pH levels (1, 2, 3, 14). Although the differences were not as striking between the Malaysian soils, there was a trend for slightly higher mobility of the herbicides in the Serdang soil which had the highest pH. The Whakatane soil, the soil exhibiting the second highest mobility, has a high organic carbon level which would result in greater herbicide adsorption and possibly reduced movement (1, 3). However, this soil is of volcanic origin and has a very high sand content (Table 1); both these attributes would lead to a high percolation rate. Higher mobility of sulfonylurea and related herbicides has been reported by many workers in sandy and sandy loam soils than in soils with a high clay content (1, 2, 3, 4, 10). The mobility of herbicides in the remaining two New Zealand soils, Hamilton and Horotiu, was similar to, or greater than that of comparable Malaysian soils. These two soils are also of volcanic origin, containing mostly allophane clay fraction, which could be conducive to increased mobility.

The average distance that the four herbicides moved in relation to the amount of water applied to the columns is presented in Table 3. The mobility of all herbicides varied with the soil type and the amount of leaching. Main effect analyses showed that effects of both the water rate and different herbicides were highly significant. However, in all except one case, the herbicide rate effect was not significant. Bensulfuron, which again exhibited the least mobility, did not leach appreciably more with increasing amounts of water and even at the highest watering regime (which leached water out of the columns) it moved a maximum of only 50 mm down the soil profile. In the case of the other three herbicides used in this study, the extent of movement increased with increasing herbicide concentration and the increasing amount of water applied to the column. These results are consistent with reports from other researchers (2, 4, 8, 10).

Table 3. Mobility of the four herbicides in two New Zealand soils as affected by amount of applied water.

| water added (ml/column)[1] | Azimsulfuron | | Bensulfuron | | Chlorimuron | | Metsulfuron | |
|---|---|---|---|---|---|---|---|---|
| | Distance leached (mm) | | | | | | | |
| | 20 | 40 | 70 | 140 | 30 | 60 | 30 | 60 |
| | | | | Horotiu sandy loam[2] | | | | |
| 370 | 80 | 80 | 15 | 22 | 42 | 62 | 87 | 87 |
| 600 | 118 | 130 | 20 | 35 | 102 | 128 | 178 | 175 |
| 900 | 145 | 164 | 23 | 30 | 147 | 160 | >260 | >260 |
| | | | | Hamilton silt loam[2] | | | | |
| 325 | 60 | 75 | 5 | 10 | 58 | 75 | 132 | 135 |
| 580 | 120 | 128 | 20 | 40 | 115 | 142 | 205 | 215 |
| 870 | 140 | 170 | 38 | 50 | 160 | 168 | >270 | >270 |

[1] Water added to wet 75% length of the column, entire length of the column and 1.5 times of the last amount.

[2] Overall l.s.d. (P=0.05) to compare any two data within a soil type is 43.4 for the Horotiu sandy loam and 26.9 for the Hamilton silt loam.

Overall, the herbicides were more mobile in the Hamilton soil than in the Horotiu soil at equivalent watering regimes. The pH levels and the sand content did not vary appreciably between the two soils, but the Horotiu soil had twice the level of organic C, which could have adsorbed the herbicides and thus reduced their movement down the soil profile. In general, the extent of movement of the herbicides, at similar concentrations, was greater in Experiment 2 than that recorded for the same two soils in Experiment 1. This was partly because the slightly drier soils used in Experiment 2 required larger amounts of water (120 - 150% of that used in Experiment 1) to wet the entire column. The relative mobility of the compounds between the two soils was however similar between the two experiments.

Results of the experiments reported here show that the distance over which a particular herbicide moves within the soil depends on water solubility of the compound, soil characteristics and the amount and intensity of water added. Overall, bensulfuron with the lowest water solubility showed very low movement in all soils, even under high watering regime. A 100 ml additon of water to the soil column approximately equates to 14 mm of rainfall. The high watering regime used in Experiment 2 is thus equivalent to 122-126 mm rainfall. As the soils used in these experiments are typical of the cropping soils in the two countries, it can be concluded that bensulfuron could be characterised a relatively immobile sulfonylurea under most conditons. Mestulfuron and azimsufluron, on the other hand, exhibited a relatively high mobility potential in the soil, sugesting that they could move down soil profiles and pose contaminaiton problems under conditons of high rainfall. These results are consistent with reports from studies by other researchers (4, 7).

The mobility data recorded in different soils indicate that the soil texture and pH level had a major effect on the transport of herbicides within the columns. The water percolation rate is higher in coarse textured soils and least in fine textured soils. Thus greater movement of most sulfonylurea herbicides has been recorded in sandy and sandy loam soils than in soils with high clay content (1, 3, 4, 10). No published information is available on comparative mobility patterns of sulfonylurea herbicides between temperate and tropical soils. Our results indicate that the New Zealand soils of volcanic origin (especially those with high sand content) appear conducive to movement and leaching of herbicides. For compounds with greater persistence and high water solubility such as metsulfuron, some movement down the soil profile in phytotoxic amounts would be expected and has been observed in previous studies (7, 8, 10).

The results also demonstrate that the technique used in this study is simple, effective and efficient for investigating the mobility of herbicides in soils. The technique is not quantitative, although estimates of herbicide concentration could be made by comparing the reduction in growth of bioassay plants with standard response curves based on known concentrations of the herbicide. By using this approach, the importance of soil type and rainfall on the mobility of herbicide through the soil profile can be predicted. The technique could be especially useful for comparing the mobility of different herbicides and can be very accurate if the herbicides belong to a group with similar chemical or biological properties.

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# PROBABILITY OF PREDICTION OF DURATION OF ACTIVITY OF AMIDE HERBICIDES IN PADDY FIELD

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*Summary*: Granule formulation of pretilachlor, thenylchlor and mefenacet were applied to paddy field just after transplanting, and herbicide dissipation and activity against paddy annual weeds were periodically observed and/or analyzed. The estimated order of duration of activity among these herbicides based on the dissipation and weed sensitivity to the herbicides were closely correlated to the observed order in the field, against (*Echinochloa oryzicola*) and bulrush (*Scirpus juncoides*). Our results indicated that the duration of activity of the amide herbicides under paddy condition could be predicted by monitoring herbicide concentration in the surface water and/or soil solution.

*Keywords*: amide herbicides, soil activity, herbicide residues

## INTRODUCTION

Duration of activity of pre-emergence herbicides are varied among herbicides and weed species under different environmental conditions, such as climate and soil. Previous studies suggested that herbicidal activity of metolachlor (7) and pendimethalin (8) by using water extraction, and thiobencarb (10) and thenylchlor (1, 4) by using centrifugation with stainless double tube (6) could be explained by the concentration in soil solution. And it may be related to the concentration in soil solution at 0-1 cm (10). It also supported other research work on herbicide behavior in soil solution in relation to its activity (2, 5, 9), and the general hypothesis that herbicides adsorbed to soil were absorbed by plants via soil solution. In this study, we are aiming at predicting the duration of activity of amide herbicides under paddy condition, in relation to herbicide residue in soil and weed sensitivity to the herbicide.

## MATERIALS AND METHODS

*Herbicide application*: The trial was conducted during 1996 in paddy field of National Agricultural Research Center (Yawara, Ibaraki, Japan). Rice (cv. Koshihikari) at 3 leaf stage was transplanted at a density of 30x15 cm on 28 May, after irrigation (24 May), puddling and leveling (27, May). Two days after transplanting, the granular formulations of pretilachlor (2%), thenylchlor (0.9%) and mefenacet (4%) were individually applied at 300/600, 600/1200, 135/270 g a.i./ha, respectively. Water was individually irrigated to each plot in order to avoid contamination among plots, and submerged condition was kept during trial period (about 50 DAA).

*Field observation*: The herbicidal activities against early watergrass (*Echinochloa oryzicola*), bulrush (*Scirpus juncoides*) and heartshape falsepikerelweed (*Monochoria vaginalis*) were periodically evaluated by visual assessment on biomass and the maximum leaf stage. In addition, the weed emergence and growth were also observed.

*Analysis of the herbicides*: The surface water and surface soil at 0-1 cm was periodically sampled from the field, and the soil was stored at -30°C until analysis. The herbicides in surface water were extracted by solid phase extraction (SepPack C18 Plus, Waters$^{TM}$) with acetone. The soil was separated into soil solution and centrifuged soil with stainless double tube at 13,000x g for 30 min. Then the herbicides in the soil solution were extracted by water/hexane separation, and that in the soil was extracted by Accelerated Solvent Extractor (ASE-200, Dionex$^{TM}$) with acetone. The herbicide concentration was determined by gas chromatography (HP6890, HP-5MS, splitless, MSD, at 70-280 °C).

*Weed sensitivity to amide herbicides*: Sea sand or soil was individually put into glass vials (25 mm diameter, 70 mm high), and each herbicide was applied with the entire response range of each weed. The pre-germinated weed seeds, such as early watergrass, bulrush and heartshape falsepikerelweed were seeded on the surface. The vials were kept in growth cabinet at 30°C with 12 h day length with fluorescent light. Several days after application, the dry weight was determined, and weed sensitivity ($I_{50}$) was calculated by non-linear regression analysis using NLIN procedure of SAS.

*Estimation of duration of activity*: In each weed and herbicide, the duration of activity was estimated by correlation between analyzed residual herbicide concentration in surface water, soil solution and centrifuged soil, and weed sensitivity value for the herbicide.

## RESULTS AND DISCUSSION

*Dissipation of the herbicides*: All three amide herbicides were dissipated in surface water, soil solution and centrifuged soil, sampled at 2, 6, 13, 22, 34, 49 days after application (DAA) (Table 1). The herbicide concentration in centrifuged soil was ten times or more than that in soil solution or surface water, except for the concentration between centrifuged soil and surface water at 2 DAA. The concentration of these herbicides in surface water were higher than that in soil solution within 1 to 2 weeks after application, and then the tendency was reversed in the later period. It supported the hypothesis of herbicide release pattern of granules, i.e. the active ingredient of the herbicides were released in surface water at once and adsorbed in surface soil. The order of the balance between soil solution and centrifuged soil was thenylchlor > pretilachlor > mefenacet. It was not of the same order of solubility in water, pretilachlor (50 ppm) > thenylchlor (11ppm) > mefenacet (4 ppm). The adsorption of these herbicides to soil (organic matter, clay) largely affects the concentration in soil solution.

Table 1. Dissipation of pretilachlor, thenylchlor and mefenacet in surface water, soil solution and centrifuged soil in paddy field.

a) pretilachlor

| DAA | Centrifuged soil (A) | | Soil solution (B) | | Surface water (C) | | Balance (%) | |
|---|---|---|---|---|---|---|---|---|
| | AVG | DEV | AVG | DEV | AVG | DEV | B/A | C/A |
| | | | | ppm | | | | |
| 2 | 1.18 | 0.109 | 0.0732 | 0.0129 | 0.7990 | 0.0457 | 6.2 | 67.7 |
| 6 | 1.42 | 0.334 | 0.0429 | 0.0106 | 0.1320 | 0.0047 | 3.0 | 9.3 |
| 13 | 0.65 | 0.077 | 0.0140 | 0.0024 | 0.0213 | 0.0048 | 2.1 | 3.3 |
| 22 | 0.34 | 0.068 | 0.0058 | 0.0017 | 0.0018 | 0.0003 | 1.7 | 0.5 |
| 34 | 0.20 | 0.032 | 0.0022 | 0.0003 | 0.0008 | 0.0001 | 1.1 | 0.4 |
| 49 | 0.10 | 0.017 | 0.0008 | 0.0002 | ND* | ND | 0.8 | - |

b) thenylchlor

| DAA | Centrifuged soil (A) | | Soil solution (B) | | Surface water (C) | | Balance (%) | |
|---|---|---|---|---|---|---|---|---|
| | AVG | DEV | AVG | DEV | AVG | DEV | B/A | B/C |
| | | | | ppm | | | | |
| 2 | 0.87 | 0.086 | 0.0305 | 0.0014 | 0.2512 | 0.0179 | 3.5 | 28.8 |
| 6 | 0.26 | 0.091 | 0.0165 | 0.0046 | 0.0091 | 0.0001 | 6.5 | 3.5 |
| 13 | 0.16 | 0.009 | 0.0049 | 0.0004 | 0.0032 | 0.0002 | 3.0 | 1.9 |
| 22 | 0.11 | 0.024 | 0.0027 | 0.0003 | 0.0011 | 0.0001 | 2.4 | 0.9 |
| 34 | 0.08 | 0.006 | 0.0011 | 0.0002 | 0.0006 | 0.0004 | 1.4 | 0.7 |
| 49 | 0.12 | 0.017 | 0.0009 | 0.0002 | ND* | ND | 0.7 | - |

c) mefenacet

| DAA | Centrifuged soil (A) | | Soil solution (B) | | Surface water (C) | | Balance (%) | |
|---|---|---|---|---|---|---|---|---|
| | AVG | DEV | AVG | DEV | AVG | DEV | B/A | B/C |
| | | | | ppm | | | | |
| 2 | 9.39 | 1.292 | 0.1473 | 0.0443 | 1.6300 | 0.2000 | 1.6 | 17.4 |
| 6 | 5.55 | 0.612 | 0.0876 | 0.0132 | 0.6615 | 0.0380 | 1.6 | 11.9 |
| 13 | 6.32 | 0.412 | 0.0487 | 0.0096 | 0.2220 | 0.0277 | 0.8 | 3.5 |
| 22 | 2.86 | 0.436 | 0.0167 | 0.0019 | 0.0007 | 0.0001 | 0.6 | 0.0 |
| 34 | 2.09 | 0.121 | 0.0048 | 0.0009 | 0.0008 | 0.0001 | 0.2 | 0.0 |
| 49 | 1.70 | 0.119 | 0.0055 | 0.0011 | ND* | ND | 0.3 | - |

* ND = not detected

*Weed sensitivity to the herbicides*: We used the $I_{50}$ value which was the most reliable in view of the sensitivity and confidence interval (Table 2). The $I_{50}$ values of mefenacet were about 10 times higher than pretilachlor and thenylchlor in sea sand and soil culture. The sensitivity was about 4-12 and 1-4 times higher in sea sand than in soil culture in early watergrass and bulrush, respectively. It may be due to higher adsorption of these herbicides to soil in comparison to sea sand. Bioassay of heartshape falsepikerelweed was not successful with sea sand.

Table 2. Weed sensitivity to pretilachlor, thenylchlor, and mefenacet with sea sand and soil culture ($I_{50}$, ppm/L).

| Weeds | Sensitivity with sea sand culture, $I_{50}$ | | | Sensitivity with soil culture, $I_{50}$ | | |
|---|---|---|---|---|---|---|
| | pretilachlor | Thenylchlor | mefenacet | pretilachlor | Thenylchlor | mefenacet |
| Early watergrass | 0.004 | 0.003 | 0.017 | 0.018 | 0.023 | 0.197 |
| Bulrush | 0.002 | 0.017 | 0.065 | 0.010 | 0.019 | 0.188 |
| Heartshape falsepikerelweed | - | - | - | 0.021 | 0.019 | 0.094 |

*Observed duration of activity*: The observed order of duration of activity against early watergrass and bulrush was pretilachlor > mefenacet > thenylchlor in Yawara paddy field in 1996, based on the visual assessment of biomass and the 2nd flush of these weeds (Table 3). However, the duration of activity against early watergrass was over 50 DAA and limited or no 2nd flush of the weed was observed at 600 g a.i./ha. We estimated the order in early watergrass mainly based on the results of a half-dose application. The observed order of duration of activity against heartshape falsepikerelweed was pretilachlor > thenylchlor > mefenacet.

*Estimated duration of activity by $I_{50}$ with sea sand or soil culture*: The estimated order of duration of activity against early watergrass and bulrush was pretilachlor > mefenacet > thenylchlor, in the case of sensitivity value ($I_{50}$) derived using sea sand and herbicide dissipation in soil solution and surface water. However, in the case of $I_{50}$ derived using paddy soil, the estimated duration of activity against these weeds were largely variable among the existing phases of the herbicides, i.e. in centrifuged soil, soil solution and surface water. The same tendency was observed with surface water in the case of $I_{50}$ from sea sand culture in early watergrass and bulrush. However, the order between thenylchlor and mefenacet was reversed between $I_{50}$ with sea sand and soil, when it was estimated with soil solution. Different order was also estimated between surface water and soil solution in heartshape falsepikerelweed. In centrifuged soil, the estimated duration of activity was over 50 days. The order of activity was variable among the three weeds.

Table 3. Comparison between observed and estimated duration of activity. The number in parenthesis (lower line) was the order of duration of activity. Lower number means longer duration of activity

| Weeds | Duration of activity (days after application) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Observed | | | Estimated | | | | | | | | | | | | | | |
| | | | | Sensitivity value by using paddy soil | | | | | | | | | Sensitivity value by using sea sand | | | | | |
| | | | | centrifuged soil | | | soil solution | | | surface water | | | soil solution | | | surface water | | |
| | PTC* | TNC | MFC | PTC | TNC | MFC | PTC | TNC | MFC | PTC | TNC | MFC | PTC | TNC | MFC | PTC | TNC | MFC |
| early water-grass | >50<br>(1**) | >50<br>(3**) | >50<br>(2**) | >50<br>(-) | >50<br>(-) | >50<br>(-) | 12<br>(1) | 4<br>(2) | <2<br>(3) | 14<br>(1) | 4<br>(3) | 13<br>(2) | 26<br>(1) | 20<br>(3) | 22<br>(2) | 19<br>(1) | 13<br>(3) | 17<br>(2) |
| Bulrush | 28-30<br>(1) | 20-22<br>(3) | 25-27<br>(2) | >50<br>(-) | >50<br>(-) | >50<br>(-) | 16<br>(1) | 6<br>(2) | <2<br>(3) | 16<br>(1) | 4<br>(3) | 14<br>(2) | 32<br>(1) | 6<br>(3) | 9<br>(2) | 22<br>(1) | 6<br>(3) | 15<br>(2) |
| Heartshape falsepikerelweed | 33-35<br>(1) | 27-28<br>(2) | 25-27<br>(3) | >50<br>(-) | >50<br>(-) | >50<br>(-) | 10<br>(1) | 5<br>(2) | 5<br>(2) | 13<br>(2) | 4<br>(3) | 14<br>(1) | -<br>(-) | -<br>(-) | -<br>(-) | -<br>(-) | -<br>(-) | -<br>(-) |

* PTC = pretilachlor, TNC = thenylchlor, MFC = mefenacet

** estimation mainly based on the results of half-dose application

*Comparison between observed and estimated duration of activity*: In case of early watergrass and bulrush by using $I_{50}$ value with sea sand, the estimated order of duration of activity among these amide herbicides were closely correlated to the order observed in the field, in relation to the herbicide dissipation in soil solution and surface water. However, the estimated durations in these herbicides were shorter than observed. On the other hand, only limited relationships were found by using $I_{50}$ value with paddy soil. A good order correlation with observed duration of activity existed in early watergrass and bulrush, in relation to the herbicide dissipation in surface water. However, in the case of soil solution, only pretilachlor, which was always predicted to have the longest duration of activity, fitted to the observed order in the field in early watergrass and bulrush. In heartshape falsepikerelweed, the order between pretilachlor and thenylchlor showed a similar tendency to the observed order. However, the estimated periods were shorter than the observed ones, and the periods for mefenacet largely varied among soil solution and surface water.

In conclusion, our results indicated that the duration of activity of the amide herbicides against early watergrass and bulrush under paddy condition could be predicted by monitoring herbicide concentration in the surface water and/or soil solution at 0-1 cm. However, the estimated duration of activity was shorter than the observed, poor correlation was found in heartshape falsepikerelweed. It is proposed that a more accurate prediction of observed durations can be achieved by introducing observed durations can be achieved by introducing uneven distribution of chemicals within 0-1 cm and revising the sensitivity value by using plant available herbicide concentrations in solution in the bioassay system. Therefore, further trials with the model system and improvement of the bioassay system targeting these issues is needed.

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# FIELD AND LABORATORY STUDIES ON THE DISSIPATION OF PRETILACHLOR AND MEFENACET UNDER LOWLAND CONDITION

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*Summary*: Field and laboratory trials to determine dissipation pattern of pretilachlor and mefenacet, both acetanilides, were conducted at the National Institute of Agro-Environmental Sciences from May-August 1996. The studies were conducted on both surface soil and paddy water in lowland conditions. In the laboratory, dissipation in soil that was previously treated with the above herbicides was compared to that where no herbicide had been applied. Under field conditions, regardless of the herbicide, dissipation in the upper soil layer was generally faster than in the lower soil layer. Dissipation in water was not very different between the two herbicides. Under laboratory conditions, the dissipation of pretilachlor in both soil and water was faster in the soil that was not previously treated with this herbicide. In contrast, the dissipation of mefenacet, in both soil and water, was faster in the soil that was previously treated with this herbicide. The computed half-life of pretilachlor in the laboratory trial using previously treated soil was 18.8 days and closely resembled the half-life in the 1-5 cm soil layer (20.2 days) in the field experiment. Similarly, the computed half-life of mefenacet in the laboratory trial using previously treated soil closely resembled the half-life in the 1-5 cm soil layer under field condition, i.e., 20.2 days and 34.3 days, respectively. For both herbicides, the half-life in water was considerably slower in the laboratory than in the field. Half-lives of the herbicides were calculated using the first-order kinetics model. In the 0-1 cm soil layer and in water, the first order kinetics appears to be adequate. However, there were indications that the first-order kinetics model did not adequately describe the dissipation pattern of both herbicides especially at the 1-5 cm and 5-10 cm layer. At these lower layers, leaching from the upper layer affected the dissipation pattern. A two-step first order kinetics or a complex first order kinetics model may describe the dissipation of these herbicides more accurately.

*Keywords* : pretilachlor, mefenacet, dissipation, half-life

## INTRODUCTION

Mefenacet and pretilachlor, especially in their granular formulation, are currently very popular in Japan. Both are used for weed control in lowland rice. The persistence of a herbicide in the soil and paddy water maybe equated to its phytotoxic activity and environmental safety. Mercado (3) reported that an effective herbicide should stay in the soil for at least 30 days. Rahman and James (4) added that a soil-acting herbicide must be able to maintain an effective concentration during the period when weed control is necessary for proper crop growth but it should not persist excessively as it may pose a threat to the succeeding crop as well as to the environment.

In Europe and America, rapid advances have been made with respect to pesticide behavior in upland soils, but not in lowland soils. In Japan, research in this area is limited (7). This paper reports results of research on the dissipation of two acetanilide herbicides in a lowland environment.

## MATERIALS AND METHODS

A field experiment to determine the dissipation of pretilachlor and mefenacet was conducted at the experiment station in the National Institute of Agro-Environmental Sciences (NIAES) from May to August 1996. Hayate (as the source of pretilachlor) and Zark-D (as the source of mefenacet) were separately applied at the rate of 4 kg formulated product/1000 $m^2$ to lowland field plots planted to rice. Soil and water samples were taken at 1, 3, 7, 14, 21, 28 and 42 days after herbicide application (DAHA). Soil samples were taken from 0-1, 1-5 and 5-10 cm layer depths. These were taken from 5 random spots in the field using a graduated stainless steel core-sampler. Water samples, on the other hand, were taken at random from several spots in the field. Soil samples were bulked according to depth and mixed thoroughly in a stainless steel bowl. Water samples were filtered using a glass micro-fiber filter (pore size, 1 μm) in an all glass vacuum filtration apparatus and the pH adjusted to between pH 6.5-7.0. Both water and soil samples were kept in appropriate glass jars and stored at -20°C until ready for residue analysis.

A laboratory trial to determine degradation rate of mefenacet and pretilachlor was conducted at the Herbicide Chemistry Laboratory at NIAES. Soil taken from the same plots where the field experiment was conducted were used in the laboratory trial. Plots coded 7-1 were not treated with herbicide. Plots coded 7-2 had been treated with pretilachlor for 2 years while plots coded 7-3 had been treated mefenacet for 6 years. The soil was sieved (5 mm) and stored at 5°C for half a year and was pre-incubated at 25°C for 1 week prior to use. Soil (15 g, dry wt. basis) was put into 200-ml capacity glass jars with 55 ml distilled water. After thorough mixing, pretilachlor (5 ppm) or mefenacet (10 ppm) was applied. Incubation was done in the dark with 23°C (day) and 20°C (night) temperature cycle. Incubation (or sampling) periods were 0, 7, 14, 28 and 42 days.

Both samples from the field experiment and the laboratory trial were analyzed for herbicide residues using the following procedure. Herbicide residues from the soil (15 g dry basis, laboratory; and 20 g, wet basis, field experiment) were extracted with 100 ml acetone; sonicated for 3 minutes and then shaken for 30 minutes. The mixture was filtered through a glass micro-fiber filter paper and the filtrate rotary evaporated to near dryness. The extract was then poured into a separatory funnel containing 30 ml of 5% NaCl solution after which 30 ml of n-hexane was added. The mixture was shaken vigorously and the hexane layer later was separated from the water. The hexane layer was then filtered through a silicone treated filter paper and the filtrate rotary evaporated to dryness. This was then re-extracted with 5-20 ml acetone and an aliquot was used for GC analysis. Water samples were extracted using a Sep-Pak C18 cartridge on a Waters concentrator pump. The "concentrated" cartridge was then dried in a Waters vacuum manifold and later eluted with 5 ml acetone 300. An aliquot of the eluate was used for GC analysis.

## RESULTS AND DISCUSSION

*Pretilachlor (Field study)*: More pretilachlor residues were observed at the 0-1 cm layer compared to the 1-5 and 5-10 cm soil layers. At the 0-1 cm layer, highest amount of residues detected was 5.22 ppm at 1 DAHA. In the 1-5 cm and 5-10 cm layers, highest residues were detected at 14 DAHA with amounts of 0.93 and 0.38 ppm, respectively. The residues in water were more than 0.01 ppm until 7 DAHA and became lower than 0.01 ppm starting from about 14 DAHA. Highest amount of residue detected in paddy water was 1.25 ppm at 1 DAHA.

The degradation rate (k) was faster in the upper than in the lower soil layer. This may indicates that there was leaching from the upper to the lower soil layers. The half-life in the 0-1 cm layer was about 3-fold and 4-fold shorter than 1-5 and 5-10 cm layers, respectively. When the amount of residues (raw data) from the 0-1, 1-5 and 5-10 cm layers were summed up and the half-life calculated, the value obtained ($DT_{50}$) was very similar to the value in 0-1 cm layer (Table 1). This suggests that computing the half-life based on the 0-10 cm layer is actually an estimation of the half-life in the 0-1 cm layer because 86% of pretilachlor exists in the 0-1 cm layer.

*Pretilachlor (Laboratory Study)*: The half-life of pretilachlor in soil where no herbicide was previously applied (soil 7-1) was about the same as that in soil where the herbicide was applied previously (soil 7-2). The half-life in water followed the same trend, i.e. it was shorter in water (from previously untreated soil, 7-1) compared to that which was previously treated (Table 1).

*Pretilachlor (Field vs. Laboratory)*: The half-life at the 0-1 cm soil layer in the field trial was about 3-folds shorter than in the laboratory trial. Half-life in water was also shorter in the field than in the laboratory. This is probably due to the effect of photo-degradation, leaching and water outflow under field conditions.

Using the first order kinetics to calculate degradation rate and half-life of pretilachlor (in the field and in the laboratory) gave considerably low $R^2$ values for the 1-5 cm, 5-10 cm, and 0-10 cm soil layer. The complex first order kinetics gave a much higher $R^2$ value and therefore maybe considered more accurate than the first order kinetics.

*Mefenacet (Field Study)*: More mefenacet residues were found at the 0-1 cm layer compared to the 1-5 and 5-10 cm soil layers. The highest amount of residues were detected at 3 DAHA with values of 13.20, 0.19 and 0.06 ppm for 0-1 cm, 1-5 cm and 5-10 cm layer, respectively. In water, the highest amount (1.07 ppm) of residue was detected at 2 DAHA. The residues in water were greater than 0.01 ppm until 21 DAHA and became less than that at around 28 DAHA.

The degradation rate (k) was faster in the upper soil layer than in the lower soil layers. Likely due to leaching from the upper to the lower soil layer. The half-life ($DT_{50}$) in the 0-1 cm layer, using the first order kinetics, was about 3-4 times shorter compared to the 1-5 and 5-10 cm layers. The $DT_{50}$ at 0-10 cm layer was almost the same as the half-life at the 0-1 cm layer (Table 2). This further indicates that the half-life in the 0-10 cm layer is an approximation of the half life in the 0-1 cm layer because 96% of the mefenacet stays at the top-most layer.

*Mefenacet (Laboratory Study)*: The half-life of mefenacet in soil where no herbicide was previously applied (soil 7-1) was >4 days longer compared to the soil where the herbicide was applied previously (soil 7-3). The same was true when we compare the half-life in water with untreated soil (water 7-1) to half-life in water with previously treated soil

(Table 2). It is possible that a greater number of mefenacet-degrading microbes were present in 7-3 than in 7-1 or the microbes in 7-3 had already adapted to mefenacet, thus, acquiring substrate specificity. However, Korpraditskul *et al.* (1) reported that long term applications (of atrazine) did not increase degradation rates.

*Mefenacet (Field vs. Laboratory)*: There was 11-15 day difference between the half-lives in soil in the laboratory trial (24.4 days, previously untreated soil; 20.2 days, previously treated soil) and the field trial (9.0 days, 0-1 cm layer). Half-life in water and 0-1 cm soil layer was shorter in the field than in the laboratory.

The first order kinetics gave lower $R^2$ values especially at the 1-5 and 5-10 cm soil layers. The complex first order kinetics generally gave much higher $R^2$ values indicating a better fit and better method for estimating the degradation of the two compounds under study.

*Pretilachlor and mefenacet*: For both herbicides, the degradation rate was faster in the upper soil layer than in the lower layers. Pretilachlor residues at the 0-1 cm layer was over 1 ppm until 7 DAHA while mefenacet residues exceeded the 1 ppm mark until 28 DAHA. This could be probably due to the higher application rate of mefenacet. Another reason maybe the faster degradation rate of pretilachlor relative to that of mefenacet. At the 5-10 cm layer, pretilachlor was not detected after 22 DAHA while mefenacet was still detectable until 42 DAHA. One supposition is that pretilachlor degrades faster under anaerobic condition than mefenacet.

## SUMMARY AND RECOMMENDATION

The degradation rate (k) was faster in the upper soil layer than in the lower soil layer. This indicates that there is leaching from the upper to the lower soil layer. Half-life in water and 0-1 cm soil layer was shorter in the field than in the laboratory probably attributable to factors such as leaching, photo-degradation, and water outflow. In the laboratory where a 0-1 cm soil was used, leaching is definitely out of the question. In addition, the laboratory trial was conducted under dark conditions thereby eliminating the effect of photo-decomposition. The effect of microorganisms on the decomposition of these herbicides under anaerobic condition needs further study to elucidate herbicide behavior below the 1 cm soil layer.

At the 0-1 cm layer, the first order kinetics initially underestimates but ultimately overestimates the degradation of both mefenacet and pretilachlor. Reyes and Zimdahl (5) made similar observations with degradation of trifluralin. LaFleur (2) also suggested that a two-step or complex-first order kinetics might provide a more suitable model for predicting residue dissipation. Srivastava and Gupta (6) proposed a biphasic first order kinetics model for predicting herbicide dissipation, which basically implies that, degradation rate is relatively faster during the first few days but tends to slow down after a certain period of time.

Studies on degradation as affected by photo-decomposition, microbial degradation, leaching, water outflow and other factors are needed to elucidate further the dissipation and degradation patterns.

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Table 1. Half life and degradation rate of pretilachlor using first order kinetics and biphasic first order kinetics. NIAES Experiment Station, 1996.

| LAYER | FIRST ORDER[a] | | | BIPHASIC FIRST ORDER[b] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | UNTIL 3 WEEKS | | | AFTER 3 WEEKS | | |
| | k | $R^2$ | half-life | k | $R^2$ | half-life | k | $R^2$ | half-life |
| 0 -1 cm[c] | 0.1025 | 0.8684 | 6.8 | 0.1699 | 0.9794 | 4.1 | 0.0310 | 0.9267 | 22.4 |
| 1 - 5 cm[d] | 0.0343 | 0.5695 | 20.2 | 0.0519 | 0.7512 | 13.4 | 0.0639 | 0.8034 | 10.8 |
| 5 - 10 cm[e] | 0.0267 | 0.5561 | 26.0 | 0.0530 | 0.9334 | 13.1 | 0.0879 | 0.9051 | 7.9 |
| Total (0-10 cm)[f] | 0.0994 | 0.5659 | 7.0 | 0.2288 | 0.9977 | 3.0 | 0.1091 | 0.9934 | 6.4 |
| Water[g] | 0.2293 | 0.9254 | 3.0 | 0.3492 | 0.9605 | 2.0 | 0.1164 | 0.9854 | 6.0 |
| LABORATORY | | | | | | | | | |
| soil 7-1 | 0.0399 | 0.9539 | 17.4 | 0.0251 | 1.0000 | 27.6 | 0.0562 | 0.9936 | 12.3 |
| soil 7-2 | 0.0368 | 0.9437 | 18.8 | 0.0233 | 0.9782 | 29.7 | 0.0537 | 0.9856 | 12.9 |
| water 7-1 | 0.0917 | 0.9679 | 7.6 | 0.1228 | 0.9950 | 5.6 | 0.0636 | 1.0000 | 10.9 |
| water 7-2 | 0.0847 | 0.9685 | 8.2 | 0.1143 | 0.9971 | 6.1 | 0.0588 | 0.9939 | 11.8 |

[a] first order kinetics = one regression line is used for the entire data set; k = degradation rate based on the slope of the regression line; half life = computed using the equation <ln(2)/k>

[b] biphasic first order = 2 regression lines were used to describe the degradation; one is for the 1st 2-3 weeks and the other for the 3rd week onwards

[c] 0-1 cm, under biphasic, until 3 weeks is actually 3-21 days; after 3 weeks is actually 21-42 days

[d] 1-5 cm, under biphasic, until 3 weeks is actually 1- 13 days; after 3 weeks is actually 13-42 days

[e] 5-10 cm, under biphasic, until 3 weeks is actually 3-13 days; after 3 weeks is actually 13-28 days

[f] Total = summation of values from 0-1, 1-5 and 5-10 cm soil layer; until 3 weeks is actually 1-7 days and after 3 weeks is actually 7-28 days.

[g] water, under biphasic, until 3 weeks is actually 2-28 days; after 3 weeks is actually 28-42 days

Table 2. Half-life and degradation rate of mefenacet using first order kinetics and biphasic first order kinetics. NIAES Experiment Station, 1996.

| LAYER | FIRST ORDER[a] | | | BIPHASIC FIRST ORDER[b] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | UNTIL 3 WEEKS | | | AFTER 3 WEEKS | | |
| | k | $R^2$ | half life | k | $R^2$ | half life | k | $R^2$ | half life |
| 0 -1 cm[c] | 0.0774 | 0.9579 | 9.0 | 0.1316 | 0.9952 | 5.3 | 0.0586 | 0.9704 | 11.8 |
| 1 - 5 cm[d] | 0.0202 | 0.1102 | 34.3 | 0.0350 | 0.9854 | 19.8 | 0.0187 | 0.2205 | 37.7 |
| 5 - 10 cm[e] | 0.0212 | 0.3415 | 32.7 | 0.1336 | 0.9051 | 5.2 | 0.0084 | 1.0000 | 82.5 |
| Total (0-10 cm)[f] | 0.0774 | 0.9391 | 9.3 | 0.1292 | 0.9919 | 5.4 | 0.0557 | 0.9596 | 12.4 |
| Water[g] | 0.1885 | 0.9707 | 3.7 | 0.2277 | 0.9803 | 3.0 | 0.0823 | 0.8216 | 8.4 |
| LABORATORY | | | | | | | | | |
| soil 7-1 | 0.0296 | 0.9725 | 24.4 | 0.0158 | 0.9781 | 43.9 | 0.0355 | 0.9968 | 19.5 |
| soil 7-3 | 0.0343 | 0.9880 | 20.2 | 0.0361 | 0.8884 | 19.2 | 0.0319 | 0.9979 | 21.7 |
| water 7-1 | 0.1042 | 0.9391 | 6.6 | 0.1880 | 0.9999 | 3.7 | 0.0701 | 0.9979 | 9.9 |
| water 7-3 | 0.1126 | 0.9244 | 6.2 | 0.2126 | 0.9978 | 3.3 | 0.0700 | 0.9993 | 9.9 |

[a] first order kinetics = one regression line is used for the entire data set; k = degradation rate based on the slope of the regression line; half life = computed using the equation <ln(2)/k>

[b] biphasic first order = 2 regression lines were used to describe the degradation; one is for the 1st 2-3 weeks and the other for the 3rd week onwards

[c] 0-1 cm, under biphasic, until 3 weeks is actually 3- 13 days; after 3 weeks is actually 13-42 days

[d] 1-5 cm, under biphasic, until 3 weeks is actually 1- 13 days (data point for day 7 excluded); after 3 weeks is actually 13-28 days

[e] 5-10 cm, under biphasic, until 3 weeks is actually 3- 13 days; after 3 weeks is actually 28-42 days

[f] Total = summation of values from 0-1, 1-5 and 5-10 cm soil layer.

[g] water, under biphasic, until 3 weeks is actually 2-28 days; after 3 weeks is actually 28-42 days

# DEGRADATION AND MOVEMENT OF ATRAZINE IN SOIL OF FAR-EASTERN RUSSIA

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*Summary*: The rate of atrazine degradation in the Meadow-Brown soil under field conditions in the first 4 weeks was considerably faster than in the subsequent weeks, with times for 50% degradation ($DT_{50}$) of 30-32 days and $DT_{90}$ of 108-109 days. Atrazine did not penetrate below 30 cm in the soil during the vegetative period and the major portion of the applied herbicide remained in the 0-10 cm layer. The field studies make it possible to conclude that there is practically no risk of groundwater contamination with residues of atrazine, if recommended application procedures are followed.

*Keywords*: atrazine, degradation, movement.

## INTRODUCTION

Atrazine was among the first herbicides to provide selective weed control in maize. It has been used extensively and at high rates in agriculture and for non-agricultural weed control. In the 1980's, the application of sensitive analytical methods revealed the presence of residues of atrazine in ground water and drinking water (1). As a consequence the "Good Farming Practice Programme" was introduced in Switzerland (and subsequently throughout Europe). Since 1990 atrazine may be used in Switzerland as follows (2): application only in maize; dosage rate 1-1.5 kg a.i./ha; application only post-emergence, but before 30 June. In these circumstances it is important to know the persistence and mobility of atrazine in the soils of Russia. In addition atrazine residues in ground water and maize were investigated.

## MATERIALS AND METHODS

In 1995 a field experiment was carried out in Far-Eastern Russia (Primorskiy region). The Meadow-Brown soil was silty clay with 2.1% organic C and a pH of 6.3. Two maize fields (10 ha) were treated with atrazine (Lentagran-kombi, 350 g a.i./L, Sandoz; Laddok, 400 g a.i./L, BASF) on 16 June, 1995. The application rate was 0.6 kg a.i./ha. The sampling dates were 19, 32, 61 and 109 days after application. Soil samples were taken at 0-10, 10-20, 20-30, 30-40 cm depth and analysed for herbicide residues by gas chromatography. Atrazine residues were also analysed in drinking water of neighbouring wells and in maize after harvesting. The total precipitation (Fig. 1) was 304 mm from 16 June until 3 October, 1995 (maize harvesting).

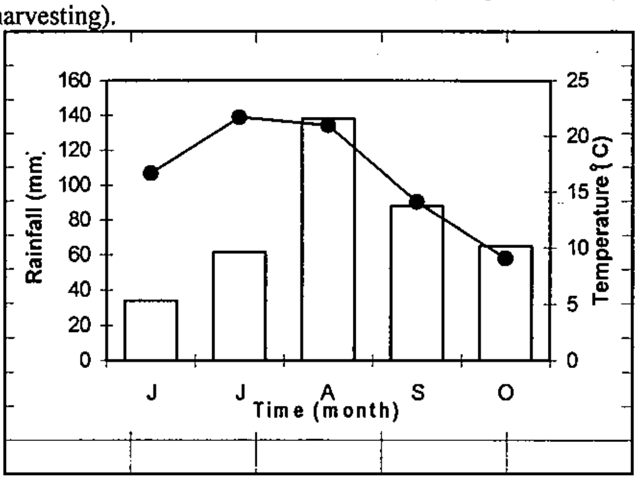


Figure 1. Monthly average soil temperature (•—•, 1 cm depth) and monthly average rainfall (□) for the field experiment in 1995.

## RESULTS AND DISCUSSION

The rate of degradation in the first 4 weeks was considerably faster than in the subsequent weeks, with times for 50% degradation ($DT_{50}$) of 30-32 days and $DT_{90}$ of 108-109 days (Figure 2). Atrazine did not penetrate below 30 cm in the Meadow-Brown soil during the vegetative period and the major portion of the applied herbicide remained in the 0-10 cm layer (Figure 3). Atrazine was not detected in drinking water of near-by wells and in maize after harvesting.

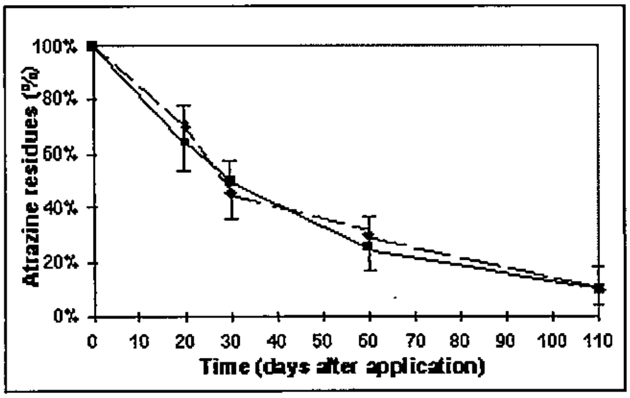


Figure 2. Atrazine degradation (% of that applied) in Meadow-Brown soil from June 1995 until October 1995: ■, lentagran-kombi; ♦, laddok

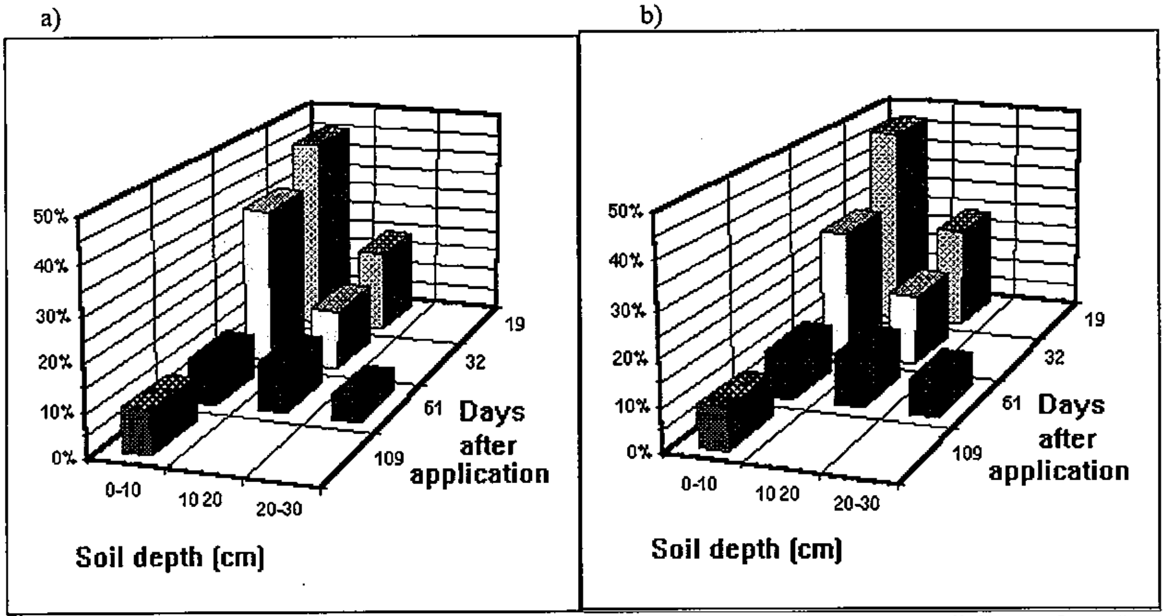


Figure 3. Distribution of atrazine residues (% of that applied) in Meadow-Brown soil layers from June 1995 until October 1995: (a) Lentagran-kombi; (b) Laddok

The field studies make it possible to conclude that there is practically no risk of groundwater contamination with residues of atrazine, if recommended application procedures are followed.

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# ASSESSING PESTICIDE POTENTIAL TO CONTAMINATE SURFACE WATER IN TROPICAL AGROECOSYSTEMS: THE IMPORTANCE OF SOIL PROPERTIES

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*Summary*: The potential risk of contamination to surface water resources from agricultural application of pesticides in the rainy tropics depends largely on their effective transport during soil erosion by water. In this study, soil properties relevant to a soil's susceptibility to water erosion were investigated using soil types collected from two different agroecosystems with a relatively long-standing history of pesticide use. Their ability to withstand the processes of soil erosion were evaluated by employing the USDA Erodibility Nomograph. The implications of the outcome of this study in predicting surface water contamination and its prospects in future conservation efforts are discussed.

*Keywords*: surface water, pesticides contamination, soil residues.

## INTRODUCTION

Soil erosion by water is the principal route for the transport of pesticides to surface water in the rainy tropics. This is made possible by the frequent occurrence of rain events (often of high intensity) which characterize this climatic condition, resulting in serious dimensions of sediments and runoff being flushed into any vulnerable surface water body. Being a universal solvent greatly enhances the transport capacity of water and does not distinguish between the phases of a pesticide during movement from one place to another in runoff processes.

Current knowledge on the environmental fate of agriculturally applied pesticides shows that their potential to contaminate surface water resources lies on the interplay of several factors which include soil properties, the local climatic conditions, physical and chemical properties of the applied pesticides, management practices and proximity of the point of application to surface water bodies (5). All of these factors may not be important to the environmental fate of a pesticide in every environmental situation. Within a given environment and for a particular pesticide, some factors are better favoured to express their properties than others and may therefore become more influential in determining how that pesticide eventually behaves. Since comprehensive environmental fate studies on a pesticide can be very expensive and time-consuming, it is of importance then to identify the dominant factors and employ them barely for the purpose of assessing the potential hazards that substances used in agriculture may inadvertently inflict on their environments. Such an endeavour will offer satisfaction to the fundamental objective of a preliminary assessment exercise which requires only a modicum of information that is sufficient to send out warning signals about pollution problems that may occur in later months or years of a farming or successive farming operations and be able to stimulate preventive thinking before commencement of land preparation. This study therefore, discusses a method which employs selected soil properties to assess the potential of a pesticide to contaminate surface water in areas proned to severe erosion due to rainfall.

## MATERIALS AND METHODS

*The Cameron Highlands Agroecosystem*: The Cameron Highlands (where soil I was obtained) is situated north of the state of Pahang in Peninsular Malaysia at an altitude of between 1,280 and 1,830 m above sea level. It covers an area of 71,218 ha of which about 7.2% is under cultivation.

It is characterized by ragged terrains and slopes that are often above $40^0$ in steepness. The soils are of granite parent material and generally sandy clay in texture. Its soil pH ranges between 4.5 and 5.5 but may be considerably higher in those areas previously treated with lime. The average monthly rainfall is between 105 and 317 mm with an average yearly rainfall of 2474 mm. The average daily relative humidity is 88%. The Cameron Highlands' dominant feature of high altitude has impacted on it a cool sub-tropical climate with mean daily temperature ranging from $14^0$ to $21^0$C; favouring the cultivation of tea, vegetables and assorted ornamental plants (flowers). Agriculture is the mainstay of the inhabitants as about 64% of the local population are farmers. The frequent occurences of precipitation and high relative humidity initiate severe erosion on denuded slopes and encourage high disease incidence. Control of pest and disease are effected by pesticides - a practice which threatens the Highlands' abundance of surface waters (2).

The Cameron Highlands consists of two main water catchment areas. They include the Telom catchment in the north and the Bertam catchment in the south. Within these catchment areas are over twenty-five streams which are tributaries of the Telom and Bertam rivers. Eight of these streams have been expanded and treated by the Malaysian Water Supply Department (Jabatan Bekalan Air) to make available potable water to residents of the Cameron Highlands and its vicinity. Agricultural activities are often concentrated close to the banks of the streams because stream water plays such vital roles in the day to day running of the farms as irrigation of farmlands during long intervals of rainfall, application of pesticides, washing of farm tools, soiled palms and feet and so on. There are huge concerns that agriculturally-applied pesticides may be transported by runoff processes from farmlands to streams because of the apparent proximity of most farms to streams, their (farms) location on steep slopes and high amount of rainfall (typical of this climatic condition).

*The MADA Agroecosystem*: The Muda Agricultural Development Authority (MADA) paddy field (where soil II was obtained) is located in the state of Kedah in Peninsular Malaysia. Its climatic condition is identical to the general weather condition in the entire state: being fed all year round with high temperature that is interrupted at intervals by rainfall of variable amount and intensity. The average monthly rainfall is between 101 and 373 mm with an average annual rainfall of 2340 mm. The average daily relative humidity and sunshine hours is 62 % and 7.02 respectively. The rainfall patterns consist of two maxima and two minima in a year. The low maximum with a mean monthly rainfall of 252 mm occurs in the months of April and May while the high maximum which occurs in October has a mean monthly rainfall of 373 mm. The low minimum with an average monthly rainfall of 101 mm occurs during the months of January and February while the high minimum which occurs in the months of March and June has a monthly rainfall of 209 mm (7). The soils are of variable parent materials and textural properties. The topographical features consist of flat to gentle sloping terrain which favours paddy cultivation. Rice is extensively grown by the inhabitants and accounts for about 21% (126,178 ha) of the total land area put to paddy cultivation in Malaysia (6). Various pest problems have been reported from this agroecosystem and most farmers are embracing chemical control to address yield losses due to pests. There are several surface water bodies located within the neighbourhood of agricultural activities. These include the rivers of Muda, Kedah, Merbok Ketil and Teliang. It is greatly feared that pesticides applied for agricultural purposes may be transported by erosion processes to nearby rivers.

*Collection of soil samples*: Surface mineral soil materials 0-15 cm were collected from Mune's Farm which is adjacent to the Malaysian Agricultural Research Development Institute (MARDI) sub-station located at Tanah Rata (Cameron Highlands) and MADA paddy field in Kedah.

*Physical and chemical analysis of soils under investigation*: Standard laboratory methods were used to conduct selected chemical and physical analyses. Included are analyses for soil properties generally considered important to a soil's susceptibility to water erosion, otherwise known as soil erodibility. The United States Department of Agriculture Nomograph requires values for the properties of texture, organic matter, structure and permeability. Organic carbon of soils were determined by Walkley-Black method (1). Percentage organic matter was calculated by multiplying organic carbon by 1.74 (1). Soil pH was determined in water (1 : 2.5 soil-water ratio), using a glass electrode and a pH meter. Particle-size distribution (mechanical analysis) was carried out by the hydrometer method described by Day (3) for clay and silt fractions. The sand fraction was separated into very coarse (2.0 to 1.0 mm), coarse (1.0 to 0.50 mm), medium (0.50 to 0.25 mm), fine (0.25 to 0.10 mm), and very fine (0.10 to 0.05 mm) components using dry sieve.

*Determination of soil erodibility factor (k) using the USDA Erodibility Nomograph*: The erodibility factor (k), was calculated for the two soil types using the Erodibility Nomograph (11). However, the mathematical representation of the nomograph was used in the calculation of the erodibility factor (k) for all soil types under nomograph determination. The mathematical representation is of the form :

$$100K = 2.1M^{1.14}(10^{-4})(12 - OM) + 3.25(S - 2) + 2.5(P - 3) \quad (1)$$

where K is the soil erodibility, M is equivalent to (percent silt + very fine sand) (100 - percent clay), OM is the percent organic matter, S is the structure code and P is the profile permeability class. For use in the nomograph, soil structure and permeability were determined from field profile description of soils carried out by Paramanathan (9).

*Determination of adsorption-desorption constants*: Adsorption and desorption studies were carried out on soils I and II as explained in another paper (2, 4).

The potential of paraquat, glyphosate and endosulfan to contaminate surface water in Cameron Highlands was assessed using Mune's Farm which was located 0.75 m from a stream. It had a size of 10 x 15 m and established on a uniform slope of 2%. The assessment tool employed was the Universal Soil Loss Equation (11):

$$A = R \times K \times LS \times C \times P \quad (2)$$

where A is the average annual soil loss (t/ha), R is the rainfall factor (j/ha), K is the soil erodibility factor (t/j), LS is the slope length and steepness factor (dimensionless), C is the cropping-management factor (dimensionless) and P is the erosion-control-supporting practice factor. (dimensionless). The rainfall factor (R) was calculated from the following equation (8):

$$Eva = 9.28P - 8838.15 \quad (3)$$

where Eva represents mean annual erosivity and P the mean annual rainfall (mm). The slope factor (LS) was computed with the following equation :

$$LS = \sqrt{l/100}\,(0.136 + 0.097s + 0.0139s^2) \quad (4)$$

where $l$ is the slope length (m) and s is the slope steepness (%). Factors C and P were assigned the value of unity based on the fact that, this assessment method was designed to be used before commencement of land preparation when planting and erosion-control practice have not been established.

## RESULTS AND CONCLUSION

Soils I and II were of sandy loam and clayey textures respectively. Organic matter contents for both soil types were within the 4 % upper range of the soils of Wischmeier *et al* for which the Erodibility Nomograph is valid. (11) (Table I).

Table 1: Erodibility factor (k) and some physico-chemical properties of soils I and II

| Quantity | Soil I | Soil II |
|---|---|---|
| pH | 7.30 | 5.40 |
| Carbon, % | 1.92 | 1.64 |
| Organic matter, % | 3.34 | 2.85 |
| Sand, % (2.00 - 0.10 mm) | 60 | 8 |
| Very fine sand,% (0.10 - 0.05 mm) | 9 | 4 |
| Silt, % (0.05 - 0.002 mm) | 23 | 33 |
| Clay, % (< 0.002 mm) | 8 | 55 |
| CEC[a] | 8.17 | 7.46 |
| Structure | 1 | 1 |
| Permeability | 2 | 6 |
| Erodibility factor (k) (t/j) | 0.18 | 0.22 |

a Cation Exchange Capacity (Cmol (+) kg-1)

Soil type II, with an estimated erodibility factor (k) value of 0.22 t/j was found to be more susceptible to the processes of soil erosion than soil type I with an estimated factor (k) value of 0.18 t/j (the higher the k value the higher the susceptibility of a soil to erosion by water). The differences in erodibility can be attributed to variations in the composition of silt and organic matter as displayed by the two soils. Soil type II had 33% and 2.85% of silt and organic matter respectively as compared with the 23% (silt) and 3.34% (organic matter) found in soil I. This result agreed with the previous findings of Morgan (8) and Wischmeier and Mannering (10), that those soils which are relatively high in silt but low in organic matter are the most erodible. When the estimated erodibility factor (k) obtained for soil type I was evaluated with other contributing factors of soil erosion by using the USLE, it predicted an annual soil loss of 148.07 t/ha which exceeds the maximum allowable annual soil loss (T) of 10 t/ha (14). Since adsorption and desorption studies indicated higher probabilities for soil type I to retain a high concentration of endosulfan (4), it implies that a stream located just 0.75 m from the farm site had a very high potential of being polluted by endosulfan because of the tendency for very high amounts of sediment to be flushed into it annually. Similar conclusions can be reached for paraquat and glyphosate whose affinities to the sandy loam (Cameron Highlands) soil were justified by their high freundlich adsorption distribution coefficients (2).

With this valuable piece of information provided to the farmer before land preparation, it becomes incumbent upon him to make necessary adjustments in his choice of practice or practices to bring predicted annual soil loss from soil erosion to tolerable level (10 t/ha). One way of accomplishing this is to make factor C in the USLE the subject of the equation and replace predicted annual soil loss (factor A) by annual tolerable soil loss (T) (C = T/R x K x LS x P). In this instance, a cover-management factor (C) that has a value of 0.15 has the capability to bring predicted annual soil loss from 148.07 t/ha to 10 t/ha (annual tolerable soil loss). The farmer can then scan through the list of soil conservation practices and their C values and select practices with C values in the range of 0.15. In the light of the outcome of this study, it can be said that: (1) those soil properties whose total effects (from their combination) determine the extent of soil loss generated from the use-site (farm land) during soil erosion and (2) those soil properties which determine the extent of retention of a pesticide by soil particles are fundamental to the assessment of a pesticide potential to contaminate surface water in tropical agroecosystems. Satisfying the above-mentioned conditions are soil properties such as texture, structure, permeability and organic matter contents. Soil texture affects the transport process of a pesticide in runoff, considering the fact that sand particles are difficult to transport because of their size but they are easily dislodged from the soil mass; clay particles are difficult to detach but are easily transported once separated from the soil mass while silt and very fine sand particles are easily detached and transported. Infiltration rate and permeability to water are rapid in sandy soils because of the high amount of macropores between sand particles, whereas the low number of macropores present in clayey and other fine textured soils make them less efficient to the infilteration and permeability of water. Structure enhances a soil's permeability to water and improves its resistance to detachment and transport through the formation of large and stable aggregates. The organic constituents of the soil which facilitate the adsorption of a pesticide at the soil surface (thereby preventing or minimising groundwater contamination) make a pesticide available for transport to surface water during soil erosion by water because of its location within the surface layer of the soil profile. Therefore, pesticides are very likely to contaminate surface water in soils high in silt (and very fine sand) and organic matter if other contributing factors of soil erosion favour the removal of topsoil in excess of annual tolerable soil loss level. It is worth stressing that, the impacts of the non-soil factors (including rainfall, topography, management and adsorption behaviour of a pesticide) are so enormous that no useful estimates of a pesticides potential to contaminate surface water can be realized from soil properties alone unless evaluated with the relevant non-soil properties as provided for by the USLE and Freundlich adsorption coefficient. This assessment method is not recommended for use in arid or semi-arid regions, with pesticides whose major route of transport is volatilization and agricultural lands experiencing erosion processes different from sheet and rill erosion. When applied within the recommended limits, this preliminary assessment effort is poised to make significant contributions to safeguarding surface waters from agricultural pollution in tropical agroecosystems.

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# DEGRADATION PATTERN AND WEED CONTROL EFFICIENCY OF ANILOFOS AND ITS EFFECT ON SOIL MICROBES IN DIRECT-SEEDED PUDDLED RICE APPLIED WITH NEEM LEAF MANURE

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*Summary:* Field experiments were carried out on the clay loam soils of the Tamil Nadu Agricultural University, Coimbatore, India during first (July-November) and second (November-March) seasons of 1988-89. The experiments were laid out in split-plot design. Main plots were applied with either 5 tones of neem leaf (*Azadiracta indica*) or 50 kg of neem cake per hectare with one no-manure treatment as absolute control. Sub-plots were applied with the pre-emergence herbicide anilofos (S (N - 4 - chlorophenyl) - N - (isopropyl - carbomoyl - methyl - O, O - dimethyl - dithiophosphate) at the rate of 0.2, 0.3, 0.4, and 0.5 kg/ha. Application of neem-leaf manure enhanced the herbicide degradation. Degradation of anilofos was very fast and no residue was detected 50 days after application. Half-life period of anilofos increased with rate of herbicide applied and ranged from four to six days. Anilofos did not show any harmful effect on soil micro-organisms. Selectivity of anilofos improved when applied with organic manure. Anilofos at 0.40 kg/ha gave effective control of grasses, sedges and broad-leaved weeds compared to all other doses. Anilofos in combination with neem-leaf manure recorded higher straw and grain yield of rice.

*Keywords:* rice, wet seeding, anilofos degradation

## INTRODUCTION

Owing to the difficulties with hand weeding, herbicides are recommended for weed control in wet-seeded rice. However, selectivity is often narrow as the seedlings of rice and weeds are at the same stage of development. Consequently, rice plants and weeds may show the same degree of susceptibility to the applied herbicides. Severe stand reduction in rice crop occurs as a result of phytotoxicity of herbicides. Weeds occupy these vacant spaces in ricefields leading to further yield loss (9).

Soil-applied herbicides apparently are degraded by microorganisms which flourish under warm moist conditions in the presence of organic matter (13). The organic matter serve as food material for microbes and resulted in population build-up (12). Degradation of herbicides was higher owing to an increase in soil microbial activity in soil rich in organic matter (7). Dissipation of acetanilides in soil indicated that microbial decomposition played a major role in its degradation. Significant volatilization of acetanilides from soil occurred only under windy conditions and when surface remains moist (1). Rice straw, compost and NPK amendments promoted degradation of thiobencarb and MCPA under upland conditions. Under flooded condition the degradation of these herbicides was slow and the various soil amendments had practically no effect on the degradation (1, 2).

In traditional rice growing areas of India, farmers are widely using neem-leaf manure for rice crop. Among the organic manures, neem-leaf is readily available and is comparatively cheaper. In addition to increased crop yields it improves soil fertility. Among the pre-emergence herbicides, next to butachlor, anilofos is widely used for transplanted rice. It is highly effective against grasses and sedge weeds. Information available on the persistence and depletion pattern of anilofos and its effect on weeds and soil microorganisms under direct-seeded puddled rice in the presence of green leaf manure is limited.

## MATERIALS AND METHODS

The experiments were laid out in a split-plot design. After dry ploughing, the field was flooded for one day and puddled twice with tractor-drawn cage-wheel. Plots were designed with a buffer spacing of 0.5 m around each plot. The main plots were applied with either 5 tons of neem-leaf or 50 kg/ha of neem-cake with one no-manure treatment as absolute control. Calculated quantities of fresh neem-leaf were applied and incorporated one week before sowing. In the case of neem-cake, it was applied a day before sowing and incorporated into the soil. Pre-germinated seeds of cv. IR 60 and IR 64 (short duration of 110 days) were sown uniformly in each plot having a thin film of water in the first and second season, respectively. The sub-plots were applied with anilofos at the rate of 0.2, 0.3, 0.4, and 0.5 kg/ha. The herbicide was mixed with sand at the rate of 50 kg/ha and applied uniformly at 8 days after sowing (DAS). The experimental plots were drained to saturated soil moisture condition before herbicide application and the same condition was maintained for 5 days after application.

Plant population was counted in a marked area of one meter square using a quadrat before and one week after herbicide application. A total quantity of 100 kg nitrogen and 50 kg each of phosphorus and potash were applied to the rice crop. Entire quantity of phosphorus was applied as basal in the form of single super-phosphate. Potash was applied in equal splits at 20 and 80 DAS in the form of muriate of potash. Nitrogen was applied in three equal splits at 20, 40 and 80 DAS in the form of urea. When the crop was fully matured, border rows of 0.5 meter all around the plot was harvested first. Sample plots were then harvested and grain yield was recorded after threshing, drying and cleaning. Grain yields were adjusted to 14% moisture. Straw from each plot was sun-dried and weighed. Anilofos residues in soil at different dates and doses were determined (14) in Gas-Liquid Chromatography. Soil samples were collected immediately after herbicide application (1 h) and at 7, 14, 21, 28, 40 DAS. Microbial populations were estimated by the dilution method. Soil extract was used for assay of bacteria, and Martin's rose Bengal agar for fungi. The dilution was $10^{-6}$ for bacteria and $10^{-3}$ for fungal populations. Total population per gram of moisture-free soil was calculated (8). Data on weed count were subjected to Log x+0.5 transformation before statistical analysis. To work out the half-life period of anilofos, probit analysis was used (4).

## RESULTS AND DISCUSSION

*Weed population:* In the first crop, grasses (*Echinocola crus-galli* (L.) Beauv., *Paspalum distichum* (Ll.) and *E.colonum* (L.) Link.) were the dominant weeds (44%) followed by sedges *Cyperus difformis* L., *C.iria* L. and *Fimbristylis miliaceae* (L) Vahl. (37%) and broad-leaved weeds *Eclipta alba* (L.) Hassak, *Ammania baccifere* L., *Marsilea quadrifoliata* L., *Monochoria vaginalis* (Burm) Perse. and *Ludwigia purviflora* Roxb. (19%), whereas in the second crop, grasses (38%) and sedges (34%) were equally dominant in the weed flora. Broad-leaved weeds occupied 27 per cent of the population. Efficiency of anilofos on weeds increased with rate of application. At 15 DAS, anilofos at 0.5 kg effectively controlled the weeds with significant differences between 0.4, 0.3 and 0.2 kg/ha. From 30 DAS onwards, anilofos at 0.4 kg registered the least weed population compared to other treatments at all stages of crop growth. (Table 1). This was due to effective control of grasses and broad-leaved weeds, particularly *Echinocola crus-galli* at the initial stage of crop growth. Whereas, anilofos at 0.5 and 0.2 kg/ha recorded lesser weed control efficiency and were at par with one another. The reduction in weed control efficiency at 0.2 kg/ha was due to the insufficient quantity of herbicide. On the other hand there was mortality of rice plants at 0.5 kg/ha which lead to increased weed competition at later stages.

Table 1. Effect of treatments on total weed population (No./m²)

| | First Crop | | | | | | Second Crop | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treat | Days after sowing (DAS) | | | | | | Days after sowing (DAS) | | | | | |
| | 15 | 30 | 45 | 60 | 75 | 90 | 15 | 30 | 45 | 60 | 75 | 90 |
| $M_1$ | 3.65 | 5.01 | 6.59 | 7.45 | 6.88 | 6.34 | 3.58 | 5.05 | 7.32 | 8.19 | 7.26 | 6.47 |
| | (14.8) | (25.7) | (44.6) | (57.1) | (47.8) | (40.7) | (14.3) | (26.6) | (55.6) | (68.3) | (52.7) | (42.2) |
| $M_2$ | 3.72 | 5.16 | 6.44 | 7.67 | 7.16 | 6.45 | 3.28 | 4.92 | 7.72 | 8.28 | 7.29 | 6.41 |
| | (14.9) | (27.3) | (42.2) | (59.6) | (51.8) | (41.7) | (11.9) | (24.8) | (60.9) | (69.4) | (54.4) | (41.3) |
| $M_3$ | 3.52 | 4.93 | 6.54 | 7.72 | 7.29 | 6.39 | 3.29 | 4.40 | 7.47 | 7.93 | 7.25 | 6.56 |
| | (13.6) | (25.0) | (44.4) | (60.7) | (53.5) | (41.0) | (11.8) | (21.5) | (58.0) | (66.2) | (54.7) | (43.6) |
| CD | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| $H_1$ | 5.15 | 6.24 | 7.54 | 8.44 | 7.95 | 7.07 | 4.61 | 6.17 | 8.36 | 9.22 | 7.95 | 6.91 |
| | (26.1) | (38.6) | (56.6) | (71.0) | (63.2) | (49.5) | (21.7) | (38.2) | (70.0) | (86.2) | (63.5) | (47.9) |
| $H_2$ | 4.07 | 4.93 | 5.83 | 7.09 | 6.66 | 6.02 | 3.95 | 5.00 | 7.24 | 7.45 | 6.88 | 6.11 |
| | (16.2) | (24.7) | (33.8) | (50.2) | (44.2) | (36.2) | (16.3) | (25.1) | (53.4) | (57.0) | (47.8) | (37.7) |
| $H_3$ | 3.28 | 4.12 | 4.95 | 6.06 | 6.04 | 5.52 | 2.75 | 3.61 | 5.85 | 6.70 | 6.74 | 6.12 |
| | (11.3) | (16.8) | (24.2) | (36.8) | (36.2) | (30.3) | (7.4) | (13.1) | (34.2) | (44.8) | (47.7) | (37.7) |
| $H_4$ | 2.03 | 4.85 | 7.38 | 8.20 | 7.78 | 7.07 | 2.22 | 4.39 | 8.17 | 9.15 | 7.50 | 6.77 |
| | (4.0) | (24.0) | (50.4) | (66.8) | (60.4) | (48.3) | (5.2) | (20.7) | (62.0) | (83.2) | (56.8) | (46.2) |
| CD | 0.76 | 0.90 | 0.65 | 0.78 | 0.79 | 0.73 | 1.01 | 1.13 | 1.11 | 1.04 | 1.05 | NS |

$M_1$- no manure, $M_2$ -neem leaf, $M_3$ -neem cake; $H_1$, $H_2$, $H_3$ and $H_4$ - anilofos at 0.2, 0.3, 0.4 and 0.5 kg /ha, respectively. Interactions were not significant at 5% level; NS-not significant; Figures in parentheses indicate original mean values.

*Plant population:* The phytotoxic effect of anilofos on rice plant increased as the rate of herbicide increased. In both the first and second crop, maximum reduction of plant population was observed at 0.5 kg (35 and 33 %) followed by 0.4 kg/ha of anilofos (15 and 14.7%, respectively). Population reduction was lowest (5%) at 0.2 kg and it was significantly different from 0.3 kg/ha. In direct-seeded flooded rice, herbicide selectivity was often marginal, because the rice and weeds were at the same stage of development. Consequently, the rice plant and weeds showed the same degree of susceptibility to applied herbicide (10). Selectivity of anilofos depends on rate of application. Increasing the rate of anilofos from 0.2 to 0.5 kg, gradually decreased the selectivity and reduction in the population of rice plants increased from 5 to 34 %. Application of neem-leaf significantly reduced the phytotoxic effect of the herbicide compared to no organic manure or neem-cake. Herbicide applied in organic manure treated plot recorded lesser phytotoxic effect on rice plants compared to no-manure treatment. The stand reduction in rice plants was only 13% in neem-leaf applied plots compared to 18% in no-manure plots (Table 2). The adsorption of soil herbicides by organic matter led to reduced crop loss (11). Faster degradation of applied herbicides by increased microbial activity in the presence of organic manure might also be one of the reasons for the good crop stand. Degradation of herbicides was faster due to increased microbial activity in soils rich in organic matter (7).

Table 2. Population reduction (%) of crop as affected by herbicide rate at 7 days after application.

| Herbicide Treatment | First Crop – Organic manure: No manure | Neem leaf | Neem cake | Mean | Second Crop – Organic manure: No manure | Neem leaf | Neem cake | Mean |
|---|---|---|---|---|---|---|---|---|
| Anilofos (0.2 kg/ha) | 5.2 | 3.1 | 5.4 | 4.6 | 6.2 | 4.3 | 5.0 | 5.2 |
| Anilofos (0.3 kg/ha) | 12.3 | 8.5 | 13.3 | 11.4 | 10.1 | 7.5 | 10.4 | 9.3 |
| Anilofos (0.4 kg/ha) | 17.4 | 12.5 | 16.1 | 15.3 | 16.7 | 12.3 | 15.1 | 14.7 |
| Anilofos (0.5 kg/ha) | 38.0 | 30.1 | 35.2 | 34.4 | 36.7 | 29.3 | 33.5 | 33.2 |
| Mean | 18.2 | 13.5 | 17.5 | | 17.4 | 13.3 | 16.0 | |
| Source | CD(p=0.05) | | | | CD(p=0.05) | | | |
| Manure (M) | 4.0 | | | | 2.8 | | | |
| Herbicide (H) | 3.2 | | | | 3.2 | | | |
| M x H | 5.3 | | | | 4.6 | | | |
| H x M | 5.6 | | | | 5.6 | | | |

*Grain and straw yield:* In the first crop, the highest grain yield of 4.5 t/ha was recorded with 0.4 kg/ha of anilofos, and it was on par with 0.3 kg/ha. Application of anilofos at highest dose recorded lesser yield. The lowest grain yield of 3.22 t/ha was observed in anilofos at 0.2 kg/ha (Table. 3) In the second crop, application of anilofos at 0.4 kg/ha recorded the maximum yield of 4.28 t/ha, which was 49 and 35% higher than with 0.2 and 0.5 kg of anilofos, respectively. The plots treated with 0.3 kg anilofos was equally effective and was comparable with the best treatment. Though the mean yield among main-plot treatments were not significant, neem-leaf produced higher yield than no-manure or neem-cake. Application of anilofos at different doses significantly influenced the straw yield. Anilofos at 0.4 kg recorded the highest straw yield followed by 0.3 kg. The lowest straw yield was registered with 0.2 kg of anilofos and it was on par with 0.5 kg/ha (Fig 1). Increase in straw yields of 27 and 23 per cent over 0.2 and 0.5 kg, respectively was obtained with 0.4 kg of anilofos. Anilofos at 0.3 kg was comparable with 0.4 kg/ha. The yield of main-plot treatments did not differ significantly. The interactions were comparable with one another.

Table 3. Effect of treatments on grain and straw yield (t/ha)

| Treatment | First Crop (t/ha): Grain yield | First Crop (t/ha): Straw yield | Second Crop (t/ha): Grain yield | Second Crop (t/ha): Straw yield |
|---|---|---|---|---|
| No manure | 3.78 | 5.88 | 3.51 | 5.57 |
| Neem leaf | 4.00 | 6.25 | 3.67 | 5.81 |
| Neem cake | 3.76 | 5.97 | 3.58 | 5.49 |
| CD(p=0.05) | NS | NS | NS | NS |
| Anilofos (0.2 kg/ha) | 3.22 | 5.51 | 2.87 | 5.00 |
| Anilofos (0.3 kg/ha) | 4.07 | 6.10 | 4.04 | 5.99 |
| Anilofos (0.4 kg/ha) | 4.51 | 6.73 | 4.28 | 6.37 |
| Anilofos (0.5 kg/ha) | 3.58 | 5.76 | 3.16 | 5.14 |
| CD(p=0.05) | 0.41 | 0.59 | 0.61 | 0.88 |

*Degradation pattern and residues in the soil:* The rate of degradation of anilofos was greater in organic-manure applied plots compared to no-manure plot. In the first crop, the residues of anilofos did not differ significantly between the main-plot treatments, immediately after application. Thereafter, the loss of herbicide was very fast in neem-leaf and neem-cake treated plot than in no-manure plot. At seven days after application 0.084 ppm of anilofos was recorded in neem-leaf, followed by 0.093 ppm in neem-cake treatment. In case of no-manure plots the amount of residue recorded was 0.155 ppm. The same trend was observed up to 28 days. At 40 days no-manure treatment alone recorded 0.001 ppm of anilofos residue in soil (Table 4 and Fig 1).

Table 4. Anilofos residues detected in soil (ppm)

| Treat/ DAA | First Crop Anilofos residue (ppm) | | | | | | Second Crop Anilofos residue (ppm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.4 | 7 | 14 | 21 | 28 | 40 | 0.4 | 7 | 14 | 21 | 28 | 40 |
| $M_1$ | 0.181 | 0.155 | 0.049 | 0.019 | 0.006 | 0.001 | 0.184 | 0.124 | 0.057 | 0.022 | 0.007 | 0.001 |
| $M_2$ | 0.176 | 0.084 | 0.028 | 0.008 | 0.003 | ND | 0.181 | 0.086 | 0.033 | 0.011 | 0.004 | 0.001 |
| $M_3$ | 0.174 | 0.093 | 0.031 | 0.010 | 0.005 | ND | 0.181 | 0.099 | 0.040 | 0.011 | 0.004 | 0.001 |
| CD | NS | 0.015 | 0.032 | 0.001 | 0.001 | NS | NS | 0.006 | 0.004 | 0.004 | 0.0012 | NS |
| $H_1$ | 0.145 | 0.079 | 0.028 | 0.007 | 0.001 | ND | 0.149 | 0.082 | 0.033 | 0.009 | 0.001 | ND |
| $H_2$ | 0.158 | 0.087 | 0.032 | 0.009 | 0.004 | ND | 0.165 | 0.096 | 0.037 | 0.012 | 0.004 | ND |
| $H_3$ | 0.180 | 0.101 | 0.036 | 0.014 | 0.005 | ND | 0.192 | 0.018 | 0.048 | 0.015 | 0.006 | ND |
| $H_4$ | 0.223 | 0.121 | 0.048 | 0.019 | 0.008 | 0.001 | 0.222 | 0.125 | 0.055 | 0.022 | 0.008 | 0.002 |
| CD | 0.023 | 0.025 | 0.006 | 0.004 | 0.002 | 0.0003 | 0.016 | 0.017 | 0.008 | 0.004 | 0.0020 | 0.001 |

DAA- Days After Application; ND - not detectable. Interactions were not significant at 5% level.

Higher residue was detected with higher doses of anilofos in all observations. The highest amount of 0.223 ppm of residue was recorded with 0.5 kg/ha, immediately after application. The least quantity of 0.145 ppm was detected in 0.2 kg/ha of anilofos. Anilofos 0.2, 0.3 and 0.4 kg in soil was degraded within a span of 28 days. The degradation time was 50 days in the case of 0.5 kg dosage. Only trace quantity (0.001 ppm) of anilofos was detected after 50 days in plots applied with 0.5 kg/ha. Similar trend was observed in the second crop also. The fast degradation could be attributed mostly to the action of soil microorganisms, which have the capacity to detoxify and inactivate herbicides present in the soil (13). In both crops, only marginal differences were observed for herbicide and organic-manure interactions. At 7 days, anilofos at 0.5 kg/ha in neem-cake and neem-leaf applied plots recorded lower amount of soil residue compared to no-manure plots. The same trend was observed at all stages.

*Half-life period of anilofos:* The half-life period of anilofos varied with the rate of herbicide applied and its interaction with organic manures. Faster degradation of anilofos in organic-manure applied plots shortened the half-life period compared to no-manure treatment. In the first crop, a loss of 50% anilofos was attained within 4.7 to 4.8 days in neem-leaf and neem-cake applied plots, whereas it took 5.3 days in no-manure plot (Table 5).

Table 5. Half-life period of anilofos in soil (days)

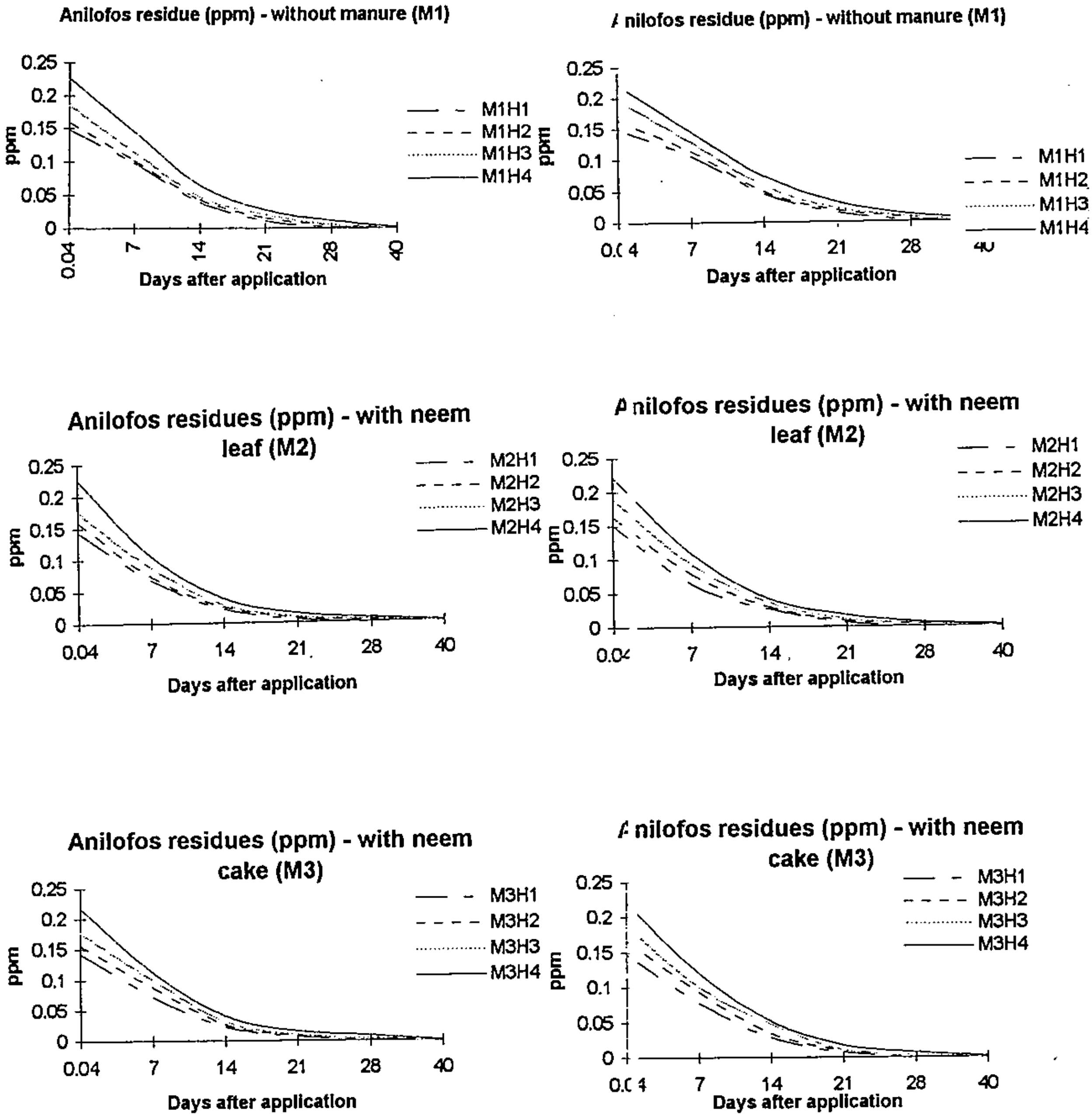
| Treat | First Crop Half-life | upper limit | lower limit | r | A | b | Second Crop Half-life | upper limit | lower limit | r | a | b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $M_1H_1$ | 4.49 | 6.37 | 2.61 | -0.97 | 1.358 | -0.067 | 4.55 | 6.89 | 2.21 | -0.96 | 1.386 | -0.066 |
| $M_1H_2$ | 5.49 | 6.97 | 4.01 | -0.99 | 1.311 | -0.055 | 5.73 | 7.51 | 3.95 | -0.99 | 1.334 | -0.052 |
| $M_1H_3$ | 5.66 | 7.23 | 4.08 | -0.99 | 1.368 | -0.053 | 5.95 | 7.58 | 4.33 | -0.99 | 1.397 | -0.051 |
| $M_1H_4$ | 5.75 | 6.59 | 4.92 | -0.99 | 1.475 | -0.052 | 6.19 | 7.14 | 5.24 | -0.99 | 1.457 | -0.049 |
| $M_2H_1$ | 4.07 | 6.18 | 1.96 | -0.98 | 1.256 | -0.074 | 4.59 | 6.50 | 2.69 | -0.99 | 1.231 | -0.066 |
| $M_2H_2$ | 4.71 | 5.39 | 4.02 | -0.99 | 1.254 | -0.064 | 4.73 | 5.49 | 3.96 | -0.99 | 1.281 | -0.064 |
| $M_2H_3$ | 4.97 | 5.63 | 4.32 | -0.99 | 1.299 | -0.061 | 5.20 | 5.88 | 4.53 | -0.99 | 1.329 | -0.058 |
| $M_2H_4$ | 5.09 | 5.38 | 4.79 | -0.99 | 1.399 | -0.059 | 5.69 | 6.27 | 5.10 | -0.99 | 1.355 | -0.053 |
| $M_3H_1$ | 3.91 | 5.09 | 2.72 | -0.98 | 1.308 | -0.077 | 3.92 | 5.38 | 2.45 | -0.98 | 1.347 | -0.077 |
| $M_3H_2$ | 4.99 | 6.06 | 3.93 | -0.99 | 1.257 | -0.060 | 5.01 | 6.00 | 4.01 | -0.99 | 1.307 | -0.060 |
| $M_3H_3$ | 5.19 | 6.11 | 4.26 | -0.99 | 1.311 | -0.058 | 5.12 | 6.53 | 3.71 | -0.99 | 1.364 | -0.059 |
| $M_3H_4$ | 5.19 | 5.84 | 4.53 | -0.99 | 1.415 | -0.058 | 5.67 | 6.25 | 5.09 | -0.99 | 1.391 | -0.053 |

r-correlation, a-intercept, b-slope.

Higher dose of anilofos recorded increased half-life period. The half-life period of anilofos at 0.2, 0.3, 0.4 and 0.5 kg/ha was 4.2, 5.1, 5.3 and 5.3 days, respectively. In the second crop, the highest half-life period of 5.6 days was recorded with no-manure followed by neem-leaf (5.1 days) and neem-cake (4.9 days) at 0.5 kg /ha of anilofos. Among the different doses of anilofos, 0.5 kg registered the longest half-life period of 5.8 days, followed by 5.4 days in 0.4 kg/ha. The lowest quantity of 0.2 kg recorded a half-life period of 4.3 days. Between the two crop seasons, the second crop recorded longer half-life period of 5.8 days compared to first crop (5.3 days) at 0.5 kg/ha of anilofos. The half-life period of anilofos increased with rate of herbicide applied. This was due to faster degradation of small quantity of chemical by soil microbes and partial absorption by crop and weeds. Higher doses of anilofos caused a set back in the build-up of microbial populations for a few days. This resulted in reduced bio-degradation and increased the half-life period of the chemical. The residues detected in the organic manure applied plots at various stages was less compared to no-manure plots. This was attributed to the increase in microbial activity in organic-manure applied plot (7).

**Fig 1. Anilofos residue (ppm) detected in soil**

First Crop | Second Crop




H1- Anilofos at 0.2 kg/ha
H2- Anilofos at 0.3 kg/ha
H3- Anilofos at 0.4 kg/ha
H4- Anilofos at 0.5 kg/ha

*Effect on bacterial population:* Application of organic manures enhanced the multiplication of bacterial population in the soil. The lowest number of bacterial colonies was recorded with no-manure treatment, whereas neem-leaf and neem-cake registered significantly more colonies in all observations. The rate of multiplication of bacterial population was almost double in the interval of seven days, at the early stage. At later stages the rate of increase was low in all the organic-manure treatments (Table. 6). Higher dose of 0.5 and 0.4 kg/ha anilofos caused reduction in total colonies upto 14 days after application of herbicide. Thereafter the multiplication of bacteria was higher compared to 0.2 and 0.3 kg/ha of anilofos.

Table 6. Effect of anilofos on bacterial population in soil (colonies per $10^{-6}$ in g of soil)

| | First Crop | | | | | Second Crop | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DAA/ | Colonies per $10^{-6}$ dilution in 1g soil | | | | | Colonies per $10^{-6}$ dilution in 1g soil | | | | |
| Treat | 0.4 | 7 | 14 | 21 | 28 | 0.4 | 7 | 14 | 21 | 28 |
| $M_1$ | 6.7 | 6.8 | 18.1 | 33.4 | 42.8 | 5.7 | 5.4 | 14.2 | 28.4 | 40.6 |
| $M_2$ | 10.6 | 16.8 | 33.3 | 50.3 | 62.8 | 9.1 | 11.8 | 24.0 | 40.2 | 51.0 |
| $M_3$ | 8.7 | 12.5 | 25.5 | 40.5 | 53.8 | 6.7 | 9.5 | 19.2 | 33.3 | 46.0 |
| CD | 1.6 | 2.3 | 5.1 | 6.1 | 8.3 | 0.4 | 1.1 | 3.1 | 4.0 | 5.2 |
| $H_1$ | 8.6 | 13.4 | 27.2 | 39.0 | 51.7 | 7.1 | 9.8 | 20.7 | 32.8 | 44.9 |
| $H_2$ | 8.8 | 12.7 | 25.9 | 41.0 | 53.1 | 7.1 | 9.4 | 19.1 | 33.1 | 45.6 |
| $H_3$ | 8.7 | 11.6 | 25.3 | 42.6 | 53.9 | 7.3 | 8.4 | 18.8 | 34.8 | 46.2 |
| $H_4$ | 8.6 | 10.4 | 24 | 43.0 | 53.8 | 7.0 | 8.0 | 18.0 | 35.1 | 46.8 |
| CD | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

Interactions were not significant at 5% level; NS-not significant

*Effect of fungal population:* Neem-leaf applied plots recorded the highest count of fungal colonies at all stages and was highly significant compared to neem-cake and no-manure treatments. The reduction in fungal population was noticed seven days after application of anilofos. After 14 days, fungal population increased at a faster rate. Rate of multiplication was higher in neem-leaf applied plots than neem-cake and no-manure treatments (Table.7).

Table 7. Effect of anilofos on fungal population in soil (colonies per $10^{-3}$ in g of soil)

| | First Crop | | | | | Second Crop | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DAA/ | Colonies per $10^{-3}$ dilution in 1g soil | | | | | Colonies per $10^{-3}$ dilution in 1g soil | | | | |
| Treat | 0.4 | 7 | 14 | 21 | 28 | 0.4 | 7 | 14 | 21 | 28 |
| $M_1$ | 11.8 | 7.8 | 13.7 | 24.0 | 31.7 | 8.6 | 5.5 | 11.5 | 21.4 | 31.1 |
| $M_2$ | 38.0 | 14.4 | 20.3 | 30.8 | 40.7 | 21.5 | 10.9 | 15.3 | 27.1 | 34.9 |
| $M_3$ | 19.3 | 9.3 | 16.7 | 25.8 | 35.4 | 17.4 | 8.9 | 13.8 | 24.5 | 31.3 |
| CD | 1.1 | 2.0 | 3.3 | 3.5 | 3.6 | 2.4 | 2.2 | 2.5 | 2.5 | 3.0 |
| $H_1$ | 22.2 | 11.7 | 17.6 | 23.7 | 34.8 | 15.8 | 9.7 | 14.2 | 23.2 | 30.2 |
| $H_2$ | 23.9 | 11.0 | 17.0 | 26.6 | 35.9 | 15.8 | 8.6 | 13.8 | 24.0 | 32.1 |
| $H_3$ | 22.8 | 10.0 | 16.7 | 27.4 | 35.9 | 16.0 | 8.0 | 13.5 | 24.5 | 33.4 |
| $H_4$ | 23.2 | 9.2 | 16.2 | 29.7 | 37.1 | 15.8 | 7.5 | 12.7 | 25.6 | 33.9 |
| CD | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

Interactions were not significant at 5% level; NS-not significant

Application of anilofos considerably reduced the initial fungal population at seven days after application of herbicide. At later stages fungal population increased in all herbicide treated plots. Different rates of anilofos had no significant influence on the fungal population. Reduction in both total bacterial and fungal populations was noticed immediately after herbicide application. This was due to temporary inhibitory effect of herbicides on soil microorganisms at the early phase. After a short lag phase, total microbial population increased several fold at later stages. Among the organic-manures, neem-leaf applied plots registered more microbial colonies at all stages. The organic matter served as a substrate and encouraged the microbial activity. The activity of microorganisms increased with the rate of neem-leaf applied to the flooded ricefield (6).

*Conclusion:* Degradation of anilofos in soil was very fast and its half-life period was only 5 to 6 days. No residue was detected 50 days after application. Anilofos had no adverse effect on soil microorganisms. Application of anilofos at 0.40 kg/ha gave effective control of grasses, sedges and broad-leaved weeds compared to the lower and higher doses. Application of neem-leaf at 5 t/ha improved the selectivity of anilofos. Anilofos in combination with neem-leaf recorded highest straw and grain yield of rice.

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# MODE OF BLEACHING PHYTOTOXICITY OF HERBICIDAL DIPHENYLPYRROLIDINONES

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*Summary*: Mode of action study of herbicidal diphenylpyrrolidinones was carried out through carotenoid analysis in intact *Scenedesmus* cells and plant-type phytoene desaturase assay using *Escherichia coli* transformant. All six diphenylpyrrodinones assayed decreased the carotenoid contents in *Scenedesmus* cells in the light as well as inhibited the plant-type phytoene desaturase. Furthermore, they never inhibited protoporphyrinogen IX oxidase at $10^{-5}$ M concentration for exceeding their $pI_{50}$-values for carotenoid decrease. Although there are some differnces in their inhibitory activity among compounds, they are now confirmed to be bleachers affecting carotenoid biosynthesis in plants.

*Keywords*: bleaching herbicides, carotenoid biosynthesis inhibitors, pyrrolidinones

## INTRODUCTION

The herbicidal diphenylpyrrolidinones, e.g. 4-ethyl-3-(3-chlorophenyl)-1-(3-isopropylphenyl)pyrrolidin-2-one, 4-ethyl-3-(3-fluorophenyl)-1-(3-trifluoromethylphenyl)-pyrrodin-2-one and others, exhibited both chlorophyl and carotenoid decrease in seedlings of *Echinochloa crus-galli*, causing the successive bleaching action on the plants, in our explorative experiments (1). Herbicides interfering with carotenoid biosynthesis are generally called carotenoid-bleachers, since absence of colored carotenoids leads to photo-oxidative degradation of chlorophylls and destruction of photosynthetic membranes. These herbicides are in sharp contrast to peroxidizing bleachers which affect chlorophyll biosynthesis and include destruction of photosynthetic pigments only in the light, indicating the so-called light dependent herbicidal action (2). In this study, we examined to confirm in which type of bleachers the herbicidal diphenylpyrrolidinones belong, using intect cells of green micro-algae, *Scenedesmus acutus* (3), and cell-free assay for plant-type phytoene desaturase prepared from an appropriately cloned *Escherichia coli* transformant (4).

## MATERIALS AND METHODS

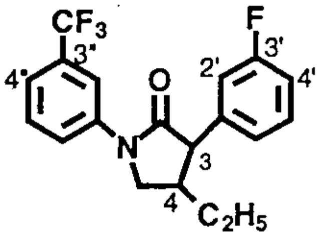
*Chemicals*: Six 4-alkyl-1,3-diarylpyrrolidin-2-ones (MTP-1 to MTP-6) were prepared by the method described elsewhere (5). Their chemical structures are shown in Table 1. Norflurazon, fluridone, fluorochloridone and diflufenican were used as the positive controls for phytoene desaturase inhibitors (Table 2).

*Inhibiton of carotenoid biosynthesis in* Scenedesmus *cells*: *Scenedesmus* cells were pre-cultured autotrophically in liquid culture medium at 22°C under gassing with 4% $CO_2$/air in the light (approx. 6000 lux). The cultures were inoculated to an optical density at 950 nm of 0.5, which is equivalent to a packed cell volume (pcv) of about 0.5 ml/ml, and the test compounds were added from a stock solution prepared in methanol so that the final concentration of methanol was maintained below 1% in the medium. The 200 ml cultures were placed in a Kniese growth apparatus for 48 h in the light (about 10000 lux), and a constant stream of air containing 4% $CO_2$ was bubbled through. After incubation, cell growth and the total carotenoid content were determined (3).

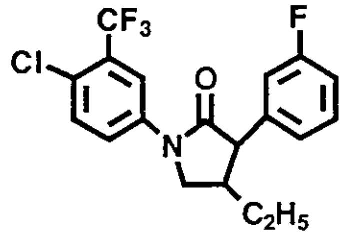
All extraction steps for carotenoids should be carried out under dim light to avoid photodegradation of the pigments. *Scenedesmus* suspension (10 ml) was centrifuged for 10 mins at 10000x g, the pellet was re-suspended in 20 ml of methanol, and 2 ml of 60% KOH (w/v) were added. Carotenoids were extracted at 65°C in darkness for 20 mins. The extract was then poured into a separatory funnel containing 25 ml of 10% diethyl-ether in petrol, and 10 ml of saturated NaCl solution was added. After the volume of the upper organic layer collected was measured, the absorbance at 445 nm was read in a spectrophotometer and an absorbance spectrum was recorded. Thus, concentration of total colored carotenoids of cell suspension was determined. The $pI_{50}$- values, the negative logarithm of the molar $I_{50}$, were used to quantify the influence of the compounds on total carotenoid contents.

Table 1. Compounds tested in this investigation

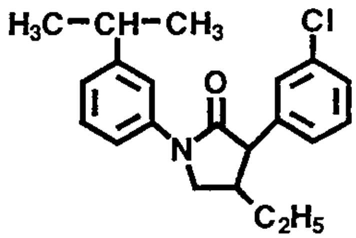
MTP-1



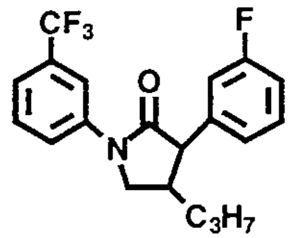
MTP-4



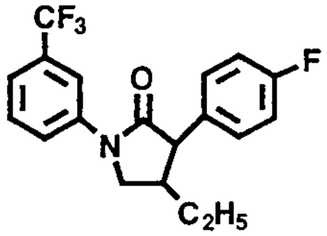
MTP-2



MTP-5



MTP-3



MTP-6

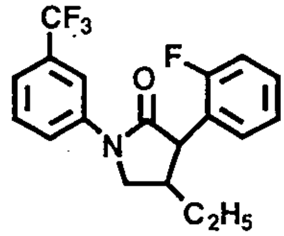
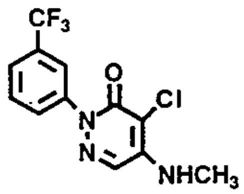
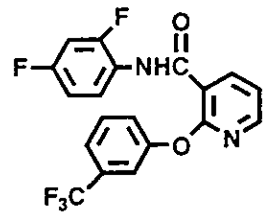


Table 2. Known carotenoid biosynthesis inhibitors

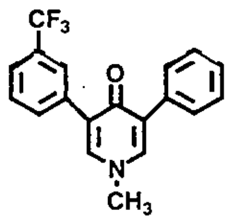
Norflurazon



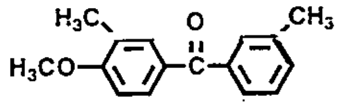
Diflufenican



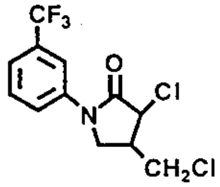
Fluridone



Methoxyphenone



Fluorochloridone



*Plant-type phytoene desaturase assay using E. coli transformant*: An active enzyme preparation of phytoene desaturase was obtained through well homogenization of the *E. coli* transformant (4). Thus, pellet of the *E. coli* cells was re-suspended in 0.1 M tris(hydroxymethyl)laminomethane/HCl buffer, pH 8.0, containing 5 mM dithiothreitol and the cells were broken with French press at 20 Mpa. The phytoene containing homogenate can be frozen for several days. For enzyme assay 0.5 ml of the homogenate was mixed with the test compounds and added in the methanol or acetone stock solution not exceeding a volume of 10 ml of organic solvent in the assay volume, and incubated at 37°C with shaking in an incubator. The reaction was terminated by addition of 2 ml of methanol. Formation of product (exactly ζ-carotene) in phytoene desaturase assay was determined spectrophotometrically by recording optical absorption spectra at 400 and 424 nm. The $pI_{50}$- values of test compounds were calculated from intersection with the abscissa in the Dixson plot.

## RESULTS AND DISCUSSION

*Carotenogenesis inhibition of herbicidal diphenylpyrrolidinones*: The inhibitory effects of herbicidal diphenylpyrrolidinones (MTP-1 to MTP-6 Table 1) and known herbicides inhibiting phytoene desaturase in carotenoid biosynthesis pathway (norflurazon, fluridone, fluorochloridone and diflufenican) on cell growth ($pI_{50}$(Sce)) and total carotenoid contents ($pI_{50}$(Caro)) in cells were assayed using autotrophic *Scenedesmus* grown in the light. Furthermore, inhibition ($pI_{50}$(PDS)) of plant-type phytoene desaturase by the compounds were assayed using *E. coli* transformant. As shown in Table 1, the $pI_{50}$(Caro) and $pI_{50}$(PDS) well correlated with $pI_{50}$(Sce) which proportionally reflects the bleaching herbicidal activity of compounds in green-house pot test (1). The term "bleaching" generally refers to decrease in the amount of photosynthetic pigments in plants in the presence of carotenoid-bleachers such as phytoene desaturase inhibitors or peroxidizing bleachers such as protoporphyrinogen IX oxidase inhibitors, as compared with the untreated control. The compound exhibiting such bleaching reaction in plant cells are now called the bleachers (6, 7). However, it should be noted that phytoene desaturase inhibitors never cause bleaching of cells and tissues which are already green, unlike peroxidizing bleachers.

All six diphenylpyrrolidinones assayed (MP-1 to MTP-6) decreased the carotenoid contents in *Scenedesmus* cells grown autotrophically in the light as well as inhibited plant-type phytoene desaturase from *E. coli* transformant. Although there were some differences in $pI_{50}$(Caro)- and $pI_{50}$(PDS)- values among compounds, they are now confirmed to be carotenoid bleachers. They never inhibited protoporphyrinogen IX oxidase at $10^{-5}$ M concentration far exceeding their $pI_{50}$-values for carotenoid decrease (Table 3). Among them, the bleaching activity of MTP-1, MTP-2 and MTP-3 was almost same as that of reference inhibitors such as norflurazon, fluridone and fluorochloridone. MTP-4, MTP-5 and MTP-6 were a little less active carotenoid bleachers compared with other compounds assayed.

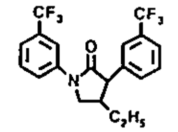
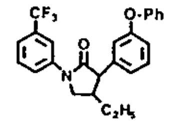
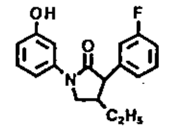
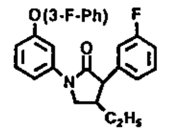
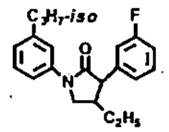
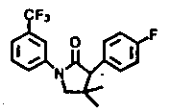
Table 3. Phytotoxic activities of carotenoid biosynthesis inhibitors determined with *Scenedesmus actus* and maize Protox

| | Inhibition (%) at $10^{-5}$ M | | | |
|---|---|---|---|---|
| | Ethane | Protox | $PI_{50}$(Caro) | $PI_{50}$(PDS) |
| Norflulazone | n.d.* | n.d.* | 7.38 | |
| Flulidone | n.d | n.d | 7.68 | |
| Fluorachloridone | n.d. | n.d. | 8.12 | |
| Diflufenican | n.d. | n.d. | 8.12 | |
| Methoxyphenone | n.d. | n.d. | 6.75 | 7.55 |
| MTP-1 | n.d. | n.d. | 7.34 | 7.54 |
| MTP-2 | n.d. | n.d. | 7.14 | 7.23 |
| MTP-3 | n.d. | n.d. | 7.26 | 7.40 |
| MTP-4 | n.d. | n.d. | 6.94 | 6.59 |
| MTP-5 | n.d. | n.d. | 5.08 | 4.96 |
| MTP6 | n.d. | n.d. | 6.12 | 5.00 |

*n.d. = not detected

*Herbicidal mode of action of diphenylpyrrolidinones*: Most carotenoid-bleachers inhibit the membrane-integrated enzyme phytoene desaturase of the carotenoid biosynthetic pathway present in plants. The enzyme assays used in cell-free mode of action studies employ $^{14}$C-labelled phytoene which can be provided only by fungal enzyme preparations started from $^{14}$C-mevalonate. In this study, the recently developed non-radioactive assay (4) for phytoene desaturase was applied in a simple spectroscopic variation to elucidate the mode of action of herbicidal diphenylpyrrolidinones. It was also convenient to determine $I_{50}$-values for enzyme inhibition (Table 4).

Table 4. Phytoene desaturase inhibition of diphenylpyrrolidinone inhibitors

| Compound | | $pI_{50}$(PDS) |
|---|---|---|
| MTP-8 |  | 6.14 |
| MTP-12 |  | 5.74 |
| MTP-17 |  | 4.62 |
| MTP-21 |  | 6.32 |
| MTP-36 |  | 5.82 |
| MTP-34 |  | 5.17 |

From the results mentioned in Section 1, it may be concluded that the primary mode of action of herbicidal diphenylpyrrolidinones in this study is interference with carotenoid biosynthesis at the level of phytoene desaturation. Enzyme kinetics studies using MTP-1 comparing with norflurazon is now revealing a reversible binding to the enzyme and non-competitive nature of the inhibitor vs. phytoene. According to this line of findings, the herbicidal diphenylpyrrolidinones assayed may be confirmed to have the same active site on phytoene desaturase as norflurazon.

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# COMPARATIVE BIOEFFICACY OF SULFOSATE AND GLYPHOSATE FOR THE CONTROL OF *ISCHAEMUM MUTICUM* (L.)

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*Summary*: The effects of sulfosate and glyphosate were compared for the control of *Ischaemum muticum* under immature rubber. At the tested rates of 1.44, 1.92 and 2.88 kg salt/ha, sulfosate consistently gave better control of the weed than glyphosate. Factorial analysis indicated that sulfosate was significantly superior than glyphosate in terms of early browning and duration of control. This paper examines the differences between the two herbicides in relation to their herbicidal characteristics.

*Keywords*: sulfosate, glyphosate, *Ischaemum muticum*

## INTRODUCTION

*Ischaemum muticum* is regarded as one of the most noxious perennial weeds in young rubber and oil palm plantings. Teo *et al.* (8) reported that this weed can cause significant reduction in oil palm yield. Its thick vegetative growth also causes great difficulty to field accessibility. Effective control using herbicides such as glyphosate and imazapyr have been reported. (2, 3).

Both sulfosate and glyphosate are non-selective post-emergence herbicides that control a wide range of weed species. Sulfosate is the trimethylsulfonium salt of *N*-phosphonomethyl glycine (PMG-trimesium) with water solubility of 1050 g/L at 20$^0$C as compared with glyphosate which is the isopropylamine form that has a water solubility of 500 g/L. Lam *et al.* (5) compared the field performance of both herbicides for the control of *Imperata cylindrica* and reported that sulfosate was superior to glyphosate in terms of early browning and duration of control. These findings were further substantiated through studies on biomass production and leaf chlorophyll analysis by Rajan *et al.* (7). The present study was conducted to investigate the effectiveness of sulfosate for the control of *I. muticum* and to compare the performance with glyphosate.

## MATERIALS AND METHODS

Two experiments were conducted on 3-year-old immature rubber. The trials were conducted in randomised complete block design with four replicates and plot size ranging from 2.5x5 m to 2.5x7 m, laid down on the inter-rows. The growth stage of *Ischaemum muticum* in both trials were highly dense with height ranging from 0.5 to 0.8 m (Experiment I) and 0.4 to 0.65 m (Experiment II). Commercially available formulations of sulfosate (Touchdown®) and 41% w/w glyphosate-isoproplyamine were applied at equivalent rates of 1.44-2.88 kg salt/ha (3-6 L product/ha) using conventional knapsack sprayer at a spray volume of 450 L/ha.

Visual assessment of % foliar control was made at 1 to 16 weeks after application (WAA). Data were subjected to anova analysis.

## RESULTS AND DISCUSSION

The results from Experiment 1 showed that sulfosate at the two lower rates of 1.44 and 1.92 kg salt/ha, particularly the later, gave better visual browning than glyphosate at 1 WAA, and gave significantly better control of *I. muticum* from 4 WAA until 16 WAA when the trial was terminated. Sulfosate at 1.44 kg salt/ha and glyphosate at 1.44-1.92 kg salt/ha did not show good control (< 70 %). However, the two herbicides gave comparable level of control at 2.88 kg salt/ha. The results are presented in Table 1.

In experiment 2, the results showed that sulfosate was faster acting than glyphosate giving significantly early browning effect at 1 WAA. The superior activity of sulfosate was evident throughout the whole trial period of 16 weeks. The level of control in this experiment was better than that achieved in the first experiment at each comparable rate. This could probably be due to the weed density which was thicker in the first experiment. The factorial analysis showed that there was no interaction between the factors, so results presented were averaged over the two herbicide rates of 1.92 and 2.88 kg salt/ha. (Figure 1).

Table 1: Visual % control of *Ischaemum muticum* by sulfosate and glyphosate.

| Treatment | Rate/ha | | % control (weeks after application) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Product (L) | Kg salt/ae | 1 | 2 | 4 | 8 | 12 | 16 |
| Sulfosate | 3 | 1.44 | 11bc | 31bc | 56b | 72bc | 66b | 44b |
| Sulfosate | 4 | 1.92 | 17b | 35bc | 69a | 82ab | 80ab | 58ab |
| Sulfosate | 6 | 2.88 | 11bc | 39b | 69a | 81ab | 85a | 63a |
| Glyphosate | 3 | 1.44 | 7c | 30c | 51b | 62d | 42c | 24c |
| Glyphosate | 4 | 1.92 | 7c | 35c | 56b | 68cd | 39c | 24c |
| Glyphosate | 6 | 2.88 | 16b | 38b | 71a | 83a | 85a | 64a |
| Paraquat | 2.8 | 0.56 | 83a | 81a | 54b | 27e | 10d | 9cd |

Means followed by the same letter are not significantly different at the 0.05 level according to LSD test.

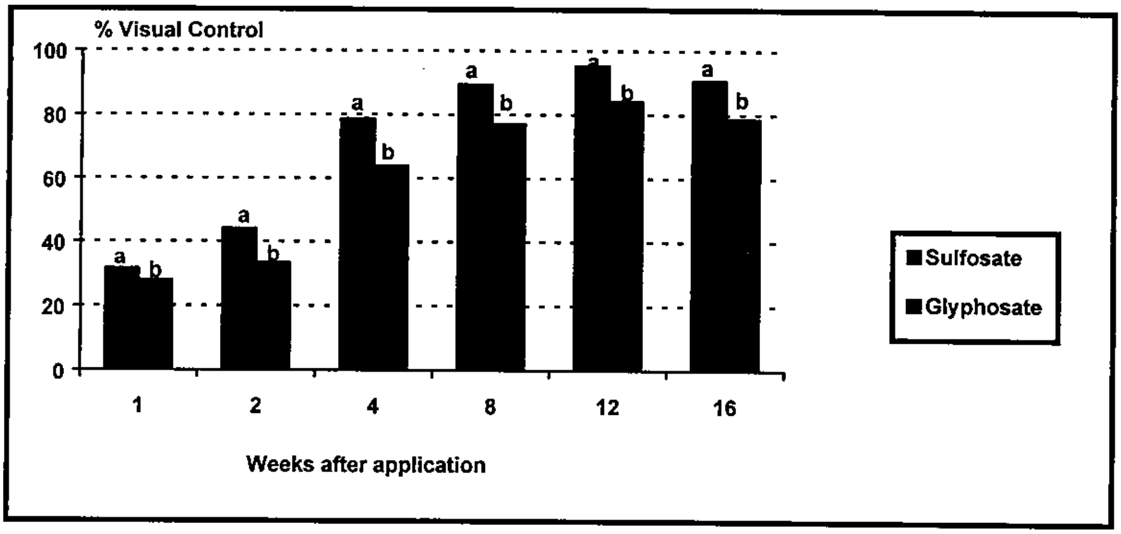


Figure 1. Effect of sulfosate and glyphosate on the control of *I. muticum.*

Sulfosate consistently showed better performance compared to glyphosate on many weed species, for example quackgrass, bermudagrass (6), lalang (5, 7), *Sorghum halepense* and *Chenopodium album* (1). Similar observations were obtained in this study on *I. muticum.*

Cooley and Foy (4) concluded that sulfosate has stronger activity and is different from glyphosate. The stronger activity of sulfosate could be due to the trimethylsulfonium (TMS) cation of sulfosate either acting in an additive or synergistic manner with the phosphonomethylglycine (PMG), or TMS acting independently of PMG to give better herbicidal activity. These findings were supported by results from Rajan *et al.* (7). The study used two commercial formulations of sulfosate and glyphosate that have different surfactants. Touchdown®, which contains sulfosate is formulated with AL2042, an alkypolyglucoside non-ionic surfactant whereas the 41% w/w glyphosate-isoproplyamine is formulated with a cationic surfactant. AL2042 appears to enhance the uniform movement and absorption of sulfosate (1), which could partly explain the better activity of sulfosate.

In conclusion, the studies indicated that sulfosate performed consistently better than the isopropylamine salt of glyphosate in the control of *I. muticum.*

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# GRAMINEAE PLANTS MAY BE CLASSIFIED INTO TWO GROUPS ON A CHIRAL RECOGNITION OF OPTICAL ACTIVE UREA COMPOUNDS

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*Summary*: The chiral urea compounds (*(R)*-MBU and *(S)*-MBU) used in this study have diverse physiological properties including 'safener' effect and growth inhibitory activities. The results on a chiral recognition of the optical active compounds in this study exhibited cross inter-genus phytotoxic and enatio-selective actions in *Gramineae* plants between the optical isomers. The *(R)*-MBU inhibited the root growth of the *Oryzoideae* plants tested, but the *(S)*-antipode inhibited those of the *Gramineae* plants except *Oryzoideae*. *Oryza* plants including wild rice and cultivated rice (*O. sativa* and *O. glaberrima*) respond similarly to chiral recognition. By contrast, the *(S)*-enantiomer strongly inhibited the root growth of the *Echinochloa* plants, and exhibited a significant inter-genus selective phytotoxicity between rice and *Echinochloa* species. An interaction between chiral recognition and taxonomy on *Gramineae* plants would be strongly suggested.

*Keywords*: chiral ureas, *Gramineae,* taxonomy, chiral recognition

## INTRODUCTION

Optical active α-methylbenzyl *p*-tolylurea compounds (*(R)*-MBU and *(S)*-MBU) which are homologues of the herbicide dymuron (α,α-dimethylbenzyl *p*-tolylurea) have diverse plant pharmacological activities. The *(R)*-enantiomer of this urea compound inhibits the growth of *Cyperaceae* weeds more than those caused by the (S) antipode. However, the *(S)*-enantiomer prevented damage to root growth of rice seedlings by Londax (bensulfuron-methyl) as the result of reduction in the herbicide uptake into rice seedlings (1). Furthermore, the *(R)*-MBU and *(S)*-MBU showed cross inter-genus selective phytotoxicity among the *Gramineae* plants, *Oryza sativa*, *Triticum aestivum* and *Echinochloa crus-galli* var. *frumentacea* Wight, on root growth inhibition in the dark (2).

In this study, we would like to mention about a chiral recognition of above optical active urea compounds from a view point of classification of *Gramineae* plants including *Oryza, Zizania, Leersia, Triticum, Hordeum, Secale, Echinochloa, Zea, Lolium, Pennisetum* and *Phaenosperma*.

## MATERIALS AND METHODS

*Plant materials*: Test plants were *Oryza sativa* L. (cv. Tsukinohikari, Akinishiki, Hoshinohikari, Toyohatamochi, Warabe hatamochi, Norin mochi-4, Mochiminori, Sensyo, Lemont, IR 26, Calrose 76, Kele, Jamuna, Dular, Red rice-d and Blu Belle), *O. glaberrima* L. (cv. Gla 25), *O. latifolia* Desv., *O. minuta* Presl., *O. rufipogon* Griff., *Zizania palustris* L. (cv. K2 and Netum), *Z. latifolia* L., *Leersia oryzoides* (L.) SW., *Triticum aestivum* L., *Hordeum distichum* L., *Secale cereale* L., *Echinochloa crus-galli* var. *frumentacea* Wight, *E. crus-galli* (L.) Beauv. var. *crus-galli, E. colonum* (L.) Link, *Sorghum bicolor* Moench., *Zea mays* L., *Lolium multiflolum*, *Pennisetum alopecuroides* L. and *Phaenosperma globosum* Munro.

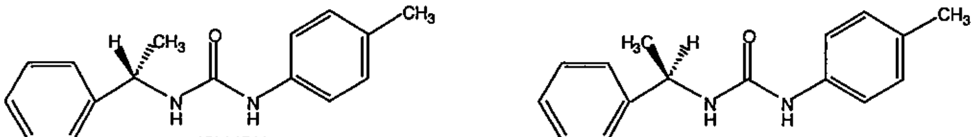
Seeds of the test plants were submersed in tap water for 1-3 days, sterilized in 3% antiformin for 5 min, washed several times with distilled/deionized water, and germinated in the dark for 48 h at 29°C. The seed coats of the wild rice (*O. latifolia, O. minuta* and *O. rufipogon*) and *P. globosum* were peeled off upon germination.

Uniformly germinated seedlings without any germinating roots were selected for all subsequent studies. On the wild rice and *P. globosum*, uniformly germinated seedlings with root length of 2-3 mm were selected. Uniform *Zizania* seedlings with a couple of crown roots (2-3 mm length) were selected and seminal roots were excised.

*Bioassay*: Germinated seeds of test plants were placed in 50 ml glass tubes containing 0.4% agar with the optical active urea compounds at concentrations of 0, 0.1, 0.3, 1, 3, 10 and 20 μM. The tubes were kept in plastic boxes saturated with moisture and placed in a dark incubator at 29°C for 3 days. A series of tests were carried out with three replications and the tests were conducted at least twice.

For *Lolium, Pennisetum* and *Phaenosperma,* a petri-dish containing 0.4% agar with (and without) the urea compounds was used for the bio-assay tests, and for *Zea* plants cotton containing the test solution was used as growth medium.

*Dose-response analysis:* Mean root length of the seedlings were expressed as percentage of control. Concentration of the chemicals causing 50% inhibition ($I_{50}$ values) were determined from the dose-response regression curve by Probit analysis.



(S)-MBU (R)-MBU

## RESULTS

The optical active compounds responded to root growth in all *Gramineae* plants tested with reduction in their length. In spite of being in the same family, there was a striking contrast on chiral recognition among them. The dose-response regression curves are shown in Fig. 1-1 for *O. sativa* (cv. Mochiminori) and for *H. distichum* (Fig. 1-8). Each regression curve was obviously reverse on a profitable enantiomer for the inhibition. The *(R)*-enantiomer strongly inhibited the root growth of *O. sativa,* whereas the *(S)*-antipode exhibited less reduction at the highest concentration (20μM) tested. This type of regression curve was typical for the *Oryzeae* plants. By contrast, the *(S)*-enantiomer was an active form and strongly inhibited the root growth of *H. distichum* at high concentrations, which was typical for *Gramineae* plants except *Oryzeae* plants.

*Response on Oryzoideae plants*: Many cultivars of *O. sativa* were assayed for their root growth under dark condition. There was a considerable difference in sensitivity among them. However, most of the rice plants tested were more sensitive to the *(R)*-enantiomer than to the *(S)*-antipode. The dose-response regression curves for various species of *O. sativa* are shown in Fig. 1. The root growth of cv. Mochiminori was strongly inhibited by the *(R)*-enantiomer at the highest concentration tested, but slightly by the *(S)*-antipode (Fig. 1-1). The shape of both growth response curves for cv. Red rice-d was very similar, in which their growth were moderately inhibited by both enantiomers but the *(R)*-MBU was more active than the *(S)*-MBU (Fig.1-2).

Growth curve for *O. glaberrima* cultivated in Africa was very similar to that of *O. sativa* plants. The *(R)*-enantiomer reduced the root length more than the *(S)*- antipode (Fig. 1-3).

The ancestral wild species of rice *(O. latifolia, O. minuta* and *O. rufipogon)* were more sensitive to the *(R)*-MBU than to the *(S)*-MBU. Response in root growth was very similar to that of cultivated rices (*O. sativa and O. glaberrima*). Especially, *O. minuta* which exhibited an interesting response to *(S)*-MBU, in which the root growth was not inhibited at all at the highest concentration tested. There was little difference in the growth of *O. rufipogon* treated with both optical isomers (Fig. 1-5).

*Zizania palustris* (cv. K2 and Netum) is an annual grass grown in flooded conditions and harvested as a major food of native Americans in areas along the Great Lakes, and *Z. latifolia* is a perennial grass along slow moving streams and lakes in moderately warm areas. These *Zizania* plants were also sensitive to the *(R)*-enantiomer and their response curves were very similar to those of *Oryza* plants. The growth was strongly inhibited by the *(R)*-MBU, showing 50% inhibition at approximately 20 μM, but 10% or less by the *(S)*-antipode (Fig. 1-6).

The root growth of *L. oryzoides*, a rice paddy weed, was inhibited by both enantiomers at concentrations above 3μM, in which the *(R)*-MBU was more effective than the *(S)*-antipode.

*Response on Arundinoideae plant*: *P. globosum* collected in South America was sensitive to the *(S)*-MBU on root inhibition. The growth was strongly reduced by the *(S)*-enantiomer at 10 μM, but only slightly at 20 μM by the *(S)*-antipode. This kind of response is in striking contrast to that on *Oryzeae* plants.

*Response on Festucoideae plants*: *T. aestivum* and *H. distichum* (Fig. 1-8), *S. cereals* and *L. multiflolum* (Fig. 1-9) are classified as *Festucoideae* plants. Their root growths were inhibited by the *(S)*-enantiomer more than by the *(R)*-antipode. This kind of response is also in striking contrast to that on *Oryzeae* plants.

*Response on Panicoideae plants*: *S. bicolor* and *Z. mays*, which are major cereals, were in contrast in the chiral recognition to *O. sativa* plants, their root growth were shortened by the *(S)*-enantiomer more than by the *(R)*-antipode.

The growth curves of *Echinochloa* plants, which are the most troublesome weeds in paddy fields over the world, had similar pattern among them, and their root growth were inhibited more by the *(S)*-enantiomer than the *(R)*-antipode. This kind of sensitivity is also in striking contrast to that on rice.

*P. alopecuroides* exhibited similar response against both enantiomers in the concentrations tested. A difference in the chiral recognition was not observed under this bioassay system due to low sensitivity to the test compounds.

## DISCUSSION

Most of the reports on correlation between optical isomerism and physiological properties of plants involve antagonism or qualitatively similar action with different quantitative potency. The chiral urea compounds (*(R)*-MBU and *(S)*-MBU) used in this study have diverse physiological properties including 'safener' effect and growth inhibitory activities. From the results on a chiral recognition of the optical active compounds in the previous and this studies, qualitatively different plant physiological activities (safener and herbicidal effects) and qualitatively similar physiological activities with cross inter-genus phytotoxic and enatio-selective actions in *Gramineae* plants were observed.

While just limited plants belonging to *Gramineae* were tested in this study, these plants may be classified into two groups on a chiral recognition of the optical active urea compounds. Only *Oryzoideae* plants (*O. sativa*, *O. glaberrima*, *Z. palustris*, *Z. latifolia*, and *L. oryzoides*) were strongly inhibited by the *(R)*-MBU, but other *Gramineae* plants tested except *Oryzoideae* were inhibited by the *(S)*-antipode. In *Oryza* plants, the wild rice (*O. sativa* and *O. glaberrima*) responded similarly to chiral recognition. Whereas, *Echinochloa* species (Fig. 1-7) were inhibited by the antipodal isomer (*(S)*-MBU). This result would indicate that the *(S)*-enantiomer, a 'safener' for rice against injury by sulfonylurea herbicides, has a significant inter-genus selective phytotoxicity between rice and *Echinochloa* species. On rice cultivation in the world, these species are considered as very troublesome weeds, especially in direct-seeded rice cultivation. The results in this study provide a new concept of a high performance and selective weed control method in rice cultivation, and strongly suggested a close relationship between chiral recognition and taxonomy in *Gramineae* plants.

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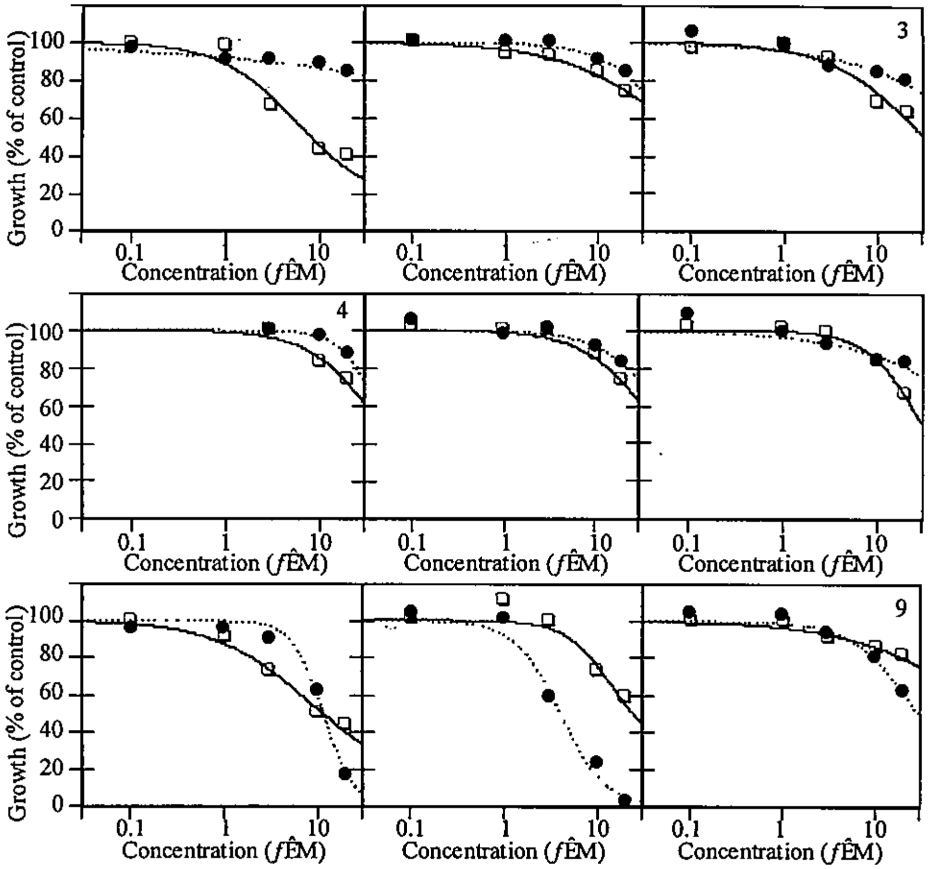


Fig. 1 Dose-response curve of *Gramineae* plants treated with the optical active urea compounds
1: *O. sativa (Mochiminori)*, 2: *O. sativa (Red rice-d)*, 3: *O. glaberrima (Gra-25)*
4: *O. latifolia*, 5: *O. rufipogon*, 6: *Z. latifolia*, 7: *E. crus-galli var. crus-galli*
8: *H. distichum*, 9: *L. multiflolum*

# CYHALOFOP SELECTIVITY IN GRAMINEOUS SPECIES

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*Summary*: Responses of seedlings of 29 Gramineae species to foliar-applied cyhalofop-butyl were examined. Fourteen species which belong to Panicoideae, except *Imperata cylindrica*, were all susceptible; being completely killed at 100 g/ha. Sensitivity of Pooideae species varied greatly. Two Oryzoideae species, rice and *Leersia oryzoides* were tolerant, surviving at 300 g/ha. Rice displayed absolute tolerance. The critical response that led to plant death appeared to be the suspension of new growth. Plant survival after this phase seemed to mainly depend on the formation of tillers. Inhibition of cell division, disorganized cell arrangement at the shoot apex and shrinking of epidermal cells of primodial leaves was induced in treated plants.

*Keywords*: cyhalofop-butyl, selectivity, Gramineae

## INTRODUCTION

Aryloxyphenoxy-propionates have been widely used as selective post-emergence grass killers in broad-leaved crops, because of their absolute selectivity between grasses and other species. Some of them were effective herbicides for grass weed control in cereals and in turf with marginal selectivity. Cyhalofop-butyl, a newly developed aryloxyphenoxy herbicide for rice (10) has been shown to give excellent control of 5-leaf stage barnyard grass seedlings without any adverse effects on rice plants (9).

Selectivity of these types of herbicides between grasses and other species is critical and can be explained by the hypothesis by Sasaki and Konishi (7) that the origin of susceptibility of Gramineae seems to lie in the specific presence of an herbicide-sensitive eukaryote form acetyl-CoA carboxylase in the plastid. On the other hand, little is known about the selectivity among Gramineae species. Although responses of grasses to some of these herbicides have been determined (1, 3, 6, 10, 11), no common trend or mechanism of selectivity within Poaceae has been found.

The objectives of this study were to determine 1) the comparative responses of 29 Gramineae species to cyhalofop-butyl; 2) the morphological changes in treated plants; and 3) whether any taxonomic and morphological differences exist between susceptible and tolerant Gramineae species.

## MATERIALS AND METHODS

*Selectivity among the gramineous species*: The experiment was conducted in a greenhouse at Kyoto University Farm, Kyoto. Twenty-eight species belonging to different genera and 3 sub-species of *Echinochloa crus-galli* were tested (Table 1). Uniform 1- to 2-leaf stage seedlings grown in seedbeds were transplanted to 1 L pots filled with sandy-loam soil/vermiculite (2/1) mixture, with 5 plants each. Pots with three 1 to 4.0 leaf stage seedlings were prepared for the herbicide treatments. Cyhalofop-butyl (30% EW) was foliar-applied at 100 g ai/ha and 300 g ai/ha at 100 ml/m$^2$ aqueous spray solution. Tween-20 at 0.05 % (w/v) was added as a spray additive. Four pots (20 plants) were used for each treatment. Plant length, leaf stage and tiller number were measured at application and 15 days later. Final number of dead plants were determined one month after application. All phytotoxic symptoms appearing on treated seedlings were recorded.

*Morphological change in the treated plants*: Corn (*Zea mays*) was selected for this experiment, because it was the most susceptible species and had the largest plant size among the grasses tested. Seedlings at 3.0-leaf stage were applied with 180 g ai/ha cyhalofop-butyl, and external and internal changes in the seedlings were observed for 7 days. The plants were grown in a growth chamber under 12/12 h light/dark and temperature at 25°C. For histological study, longitudinal sections of the shoot apex at 4 and 7 days after application were obtained by the paraffin embedding method.

## RESULTS AND DISCUSSION

*Selectivity:* Twenty-nine species in 26 genera were classified into 3 groups according to their susceptibility to the herbicide (Table 1). All species belonging to sub-families of Panicoideae (except for *Imperata cylindrica*; including four barnyard grasses, *Echinochloa oryzicola* and 3 sub-species of *E. crus-galli*) and Eragrostoideae , namely warm season species, were most susceptible and completely controlled at 100 g/ha. In contrast, rice (*Oryza sativa*) and *Leersia oryzoides* which belong to Oryzoideae sub-family showed little or no susceptibility even at 300 g/ha, although they are warm season species. The species belonging to the Pooideae sub-family, namely cool season species, varied widely in their responses to cyhalofop-butyl; All seedlings of *Alopecurus aequalis* and *Agrostis alba* were killed at 100 g/ha, while those of timothy (*Phleum pratense*), *Agropyron repens*, barley (*Hordium vulugale*), wheat (*Triticum aestivum*) and *Bromus tectorum* survived at 300 g/ha. Among the 29 species tested, rice displayed the highest tolerance. Rice seedlings treated with 300 g/ha cyhalofop-butyl did not exhibit any difference from untreated seedlings, while all other species, whether they were susceptible or tolerant, exhibited phytotoxic symptoms to a greater or lesser extent.

It is notable that in this study those regarded as C4 plants as classified by Elmore and Paul (2), except *I. cylindrica* were all susceptible to cyhalofop-butyl, while only 2 of the 14 C3 plants were highly susceptible. Cyhalofop selectivity seems to largely coincide, in some ways, with that reported on other aryloxyphenoxy herbicides and sethoxidim (1, 3, 6, 11). These facts suggest that the $CO_2$ reduction pathway in photosynthesis might be involved in differential responses of Gramineae species to these types of herbicides.

Table 1. Sensitivity of 29 Gramineae species to cyhalofop-butyl*.

| Most susceptible | Relatively susceptible | Tolerant | Absolutely tolerant |
|---|---|---|---|
| *Echinochloa oryzicola* | *Avena sativa* | *Imperata cylindrica* | *Oryza sativa* |
| *E. crus-galli, var. crus-galli* | *Lolium perenne* | *Pao annua* | *Bromus tectorum* |
| *E. crus-galli, var. praticola* | *Festuca arundinacea* | *Phleum pratense* | |
| *E. crus-galli, var. formosesis* | *Dactylis glumerata* | *Agropyron repens* | |
| *Setaria faberi* | | *Hordium vulgare* | |
| *S. italica* | | *Triticum aestivum* | |
| *Digitaria ciliaris* | | *Leersia oryzoides* | |
| *Panicum bisulcatum* | | | |
| *Paspalum notatum* | | | |
| *Pennisetum alopecroides* | | | |
| *P. setosum* | | | |
| *Sorghum halepense* | | | |
| *Zea mays* | | | |
| *Leptpchloa chinensis* | | | |
| *Eleusine aequalis* | | | |
| *Agrostis alba* | | | |

* Species were classified according to the responses of 3 to 4- leaf stage seedlings to 100 g and 300 g ai/ha cyhalofop-buytl; Most susceptible- completely controlled at 100 g; relatively susceptible- completely controlled at 300 g but some survived at 100 g; tolerant- all survived but inhibited in growth at 300 g; absolutely tolerant- no response.

*Morphological changes*: In the first experiment typical morphological changes observed in the treated shoots were common across species, regardless of the sensitivity to the herbicide. The fourth leaves and the youngest folded leaves, became withered and finally dried up. The rapidly elongating third leaves stopped growing and chlorosis occurred more or less in the lower part of the leaf blades. The already matured second leaves, were changed little by the treatments and maintained their green colour.

In contrast, new development after treatment differed between the species. In the tolerant species other than rice, tiller formation was not inhibited or rather was promoted with 100 and 300 g/ha cyhalofop-butyl treatments, although growth of main shoots in surviving plants tended to be inhibited. In *I. cylindrica* and *L. oryzoides*, the perennial grasses, new lateral growth was not by tillering but the formation of rhizomatous shoots.

Corn seedlings treated with 180 g/ha cyhalofop-butyl completely ceased the elongation of all emerged leaves within 2 days after application. Withering followed by necrosis of the basal parts of un-emerged fourth leaves and shrinking outer layers of epidermal cells in the fifth to seventh primordial leaves, started 4 days after application. Cell division at the apical meristem and internodes in the shoot apex completely stopped within 4 to 7 days after application. Disorganized cell arrangement, and shrinking of cells and nuclei were also observed. Meristematic cells in the axillary buds were less affected than those in the apical meristem. These morphological and histological changes caused by cyhalofop-butyl were very similar to those observed in plants treated with sethoxidim, fluazifop and fenoxaprop (4, 5, 8).

The above results indicate that one of the important factors that influence sensitivity must be the activity of lateral growth which was dependent on species and the growth stage. The beginning of tiller formation might be the critical point for reduced sensitivity to cyhalofop-butyl.

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# USE OF ADJUVANTS WITH NICOSULFURON FOR CONTROL OF *PASPALUM DISTICHUM* IN MAIZE

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*Summary*: *Paspalum distichum* is a perennial grass weed that over-winters as dormant stolons and is a problem in many maize crops in New Zealand. The herbicide nicosulfuron has been shown to be effective in controlling a variety of both broad-leaved and grass weeds but not *P. distichum*. Experiments conducted on potted plants using 20 different adjuvants identified two ethoxylated tallow amine products, Ethokem and Frigate, that greatly enhanced the control of *P. distichum* with nicosulfuron. However, these adjuvants also reduced the tolerance of the maize and resulted in some leaf discolouration and occasional stunting.

*Keywords*: nicosulfuron, *Paspalum distichum*, adjuvants

## INTRODUCTION

The sulfonylurea herbicide nicosulfuron has been demonstrated to give post-emergence control of several difficult to control grass weeds in maize and soybean crops. For example the grass weeds *Elytrigia repens* (L.) (quackgrass or couch), *Sorghum halepense* ((L.) Pers.) (Johnson grass) *and Setaria faberii* (Herrm.) (giant foxtail) are all readily controlled by 35-53 g ai/ha of nicosulfuron (14, 19). When used with specific adjuvants, nicosulfuron has also been reported to control a range of broad-leaved weeds in maize (4, 7).

In New Zealand the perennial grass *Paspalum distichum* (L.) (knotgrass or jointgrass) is a serious problem weed in many maize growing areas especially in high organic matter or peaty soils, low lying areas and adjacent to drains. Nicosulfuron used alone was found to result in only moderate phytotoxicity on this weed in several field trials (11). Adjuvants, i.e. chemicals that enhance herbicidal activity, have been shown to increase the efficacy of sulfonylurea herbicides (9, 10). In particular, nicosulfuron has been demonstrated to be more responsive to the use of adjuvants than other sulfonylureas (18), but specific adjuvants need to be recommended for specific weeds (3, 17).

The objectives of the experiments reported here were to evaluate several adjuvants of different types for use with nicosulfuron to improve the control of P. distichum, and to test the tolerance of young maize plants to these mixtures.

## MATERIALS AND METHODS

Two experiments using potted plants of *P. distichum* were conducted during the summers of 1995/96 and 1996/97. At the same time, potted maize (*Zea mays*) plants were used to evaluate the same treatments for crop tolerance. Both *P. distichum* and maize were grown in 150 mm diameter plastic pots in a Horotiu sandy loam soil (5.3% organic carbon, 68% clay, 25% silt, 6% clay and a pH of 5.8). There was a single *P. distichum* plant per pot and four maize plants per pot. The *P. distichum* was grown outdoors to ensure that the plants were hardened and maintained close to field conditions. The maize plants (var. Pioneer 3527) were grown in the glasshouse. All plants were given supplementary nutrients and soil moisture levels were maintained close to field capacity. All the treatments were made up in 1 L volumetric flasks according to label instructions and applied with a $CO_2$ powered, moving belt pot-sprayer equipped with a single TeeJet 8002E nozzle and delivering 300 L/ha at 210 kPa.

In the first experiment, rooted stolons of *P. distichum* were planted on 4 April, 1995 and allowed to over-winter outdoors in the pots. These plants were sprayed in spring on 2 October, 1995 when they had 6 to 10 new leaves and had grown new stolons of 5-15 cm length. The maize plants that were sprayed at the same time were planted on 8 September, 1995 and were 30-40 cm tall with 4 leaves when treated. This experiment compared the efficacy of nicosulfuron at 80 g a.i./ha used alone and in combination with 20 different adjuvants. The adjuvants included organosilicones, cationic and non-ionic surfactants, petroleum oil concentrates, vegetable oil derivatives and tallow derivatives. Each treatment was replicated four times for both *P. distichum* and for the maize.

In the second experiment, rooted stolons of *P. distichum* were planted in pots in spring on 6 September, 1996 and sprayed on 23 December, 1996 when the plants had stolons up to 20 cm long and 10 to 15 leaves. The maize plants that were sprayed at the same time were planted on 15 November, 1996 and were 15-18 cm tall with 6 or 7 leaves. This experiment evaluated the six best adjuvants from the previous study. Each adjuvant was used at two rates in combination with nicosulfuron at 80 g/ha. Nicosulfuron was also used alone at 80 and 160 g/ha. Each treatment was replicated 15 times for *P. distichum* and 8 times for the maize. The adjuvants used were Ethokem (polyethanoxy alkyl amine, Techsol) a cationic surfactant, which has also been described as a tallow amine ethoxylate (20); Weed Master CT Surfactant (tallow amine ethoxylate 60%, Nufarm); Uptake (crop oil concentrate (COC), a proprietary blend of paraffinic oil and alkyl phenolic glycol ether, DowElanco (NZ) Ltd); Shell Emulsifiable Oil (paraffinic petroleum oil plus emulsifier, Shell); Frigate (fatty amine ethoxylate, ISK); and Armoblen 650 (alkoxylated tertiary fatty amine plus a sorbitan surfactant, AKZO).

In both experiments, the treated plants were regularly assessed for damage by two or three observers. In Experiment 1, *P. distichum* was assessed every 2 weeks until the living top growth of the plants was harvested, dried and weighed 2 months after treatment. The maize was assessed twice weekly until the top growth was harvested, dried and weighed 17 days after treatment (d.a.t.). In Experiment 2, *P. distichum* was assessed 16 and 28 d.a.t. and the regrowing top growth was harvested, dried and weighed 10 weeks after treatment. The maize was assessed twice weekly until the top growth was harvested, dried and weighed 18 d.a.t.

As Experiment 1 had a large number of treatments and only four replicates, an analysis of variance (ANOVA) did not adequately separate the means. Therefore, the adjuvants were grouped into similar types and the data re-analysed. For Experiment 2, all data were also analysed using ANOVA. The *P. distichum* dry matter data was square-root transformed before analysis to control for heterogeneity of variance. The arithmetic means and an average l.s.d. are presented, but all conclusions are drawn from the analysis of the transformed data.

## RESULTS AND DISCUSSION

The results from the first experiment, with the adjuvants grouped according to type, are presented in Table 1. These show that several of the adjuvant we tested had no better efficacy on *P. distichum* than the herbicide alone. However, two classes of adjuvant, cationic surfactants and tallow amine derivatives, demonstrated increased and accelerated brownoff of *P. distichum* and considerably less regrowth, with most plants dying by the finish of the experiment. The four adjuvants in these two groups were Ethokem, Weed Master CT surfactant, Armoblen 650 and Frigate. Further, the two mineral oil type adjuvants, Shell Emulsifiable Oil and Uptake, resulted in significantly less regrowth although their initial brownoff was slower.

Table 1. Damage scores and final dry matter yield for *P. distichum* and maize plants treated with nicosulfuron at 80 g a.i./ha and various adjuvants.

| Adjuvant class | Number of adjuvants in class | *P. distichum* Percent damage (14 d.a.t.) | *P. distichum* Percent damage (28 d.a.t.) | *P. distichum* Dry matter (g/pot) | Maize Percent damage (8 d.a.t.) | Maize Dry matter (g/pot) |
|---|---|---|---|---|---|---|
| Untreated | 0 | 0 | 0 | 12.17 | 0 | 3.61 |
| Herbicide alone | 0 | 40 | 70 | 2.07 | 0 | 3.34 |
| Cationic surfactant | 1 | 63 | 95 | 0.0 | 8 | 3.23 |
| Non-ionic surfactant | 7 | 50 | 61 | 1.02 | 0 | 3.54 |
| Organosilicone | 5 | 40 | 71 | 0.70 | 2 | 3.34 |
| Plant oil derivative | 2 | 37 | 62 | 0.64 | 1 | 3.36 |
| Mineral oil derivative | 2 | 46 | 80 | 0.12 | 2 | 3.27 |
| Tallow amine derivative | 3 | 55 | 92 | 0.07 | 3 | 3.25 |
| l.s.d. (P=0.05) | | 11 | 15 | 1.46 | - | 0.39 |

Some of the adjuvants appeared to slightly suppress the growth of maize plants but the dry matter weights showed no significant differences between treatments. However, some adjuvants did cause unsightly discolouration to the leaves. Ethokem gave yellow mottling on the uppermost part of the plant which would have received the highest concentration of the spray mix. This mottling turned white with time. Frigate resulted in a more general reddish discolouration of the whole plant.

The six best adjuvants from Experiment 1 were evaluated further in Experiment 2 the following year (Tables 2 and 3). Each of these adjuvants was used at the full recommended rate and also at a half-strength rate. Also included was a double rate of nicosulfuron (160 g/ha) for comparison with the adjuvant combinations. When used at the full rate, all adjuvants except the two mineral oils (Shell Emulsifiable Oil and Uptake) significantly increased the activity of nicosulfuron. This enhanced level of activity was similar to that of the double rate of herbicide except in the case of Frigate, where control of *P. distichum* was even better. When used at the half-rate, the performance of four of the adjuvants was equal to that at the full rate. For the other two, Armoblen 650 and Weed Master CT Surfactant, the half rate resulted in significantly reduced control that was no better than the herbicide alone. In Experiment 2, Shell Emulsifiable Oil and Uptake did not perform as well as in the first experiment, possibly because of the longer period of time that the *P. distichum* was allowed to regrow before harvesting. In both experiments all treatments stopped the growth of *P. distichum* for at least a month. After this the plants often began to slowly regrow, the growth rate increasing with time. Only in the Ethokem and Frigate treatments were the plants completely dead and rotting at the end of the experiment. Both Frigate and Ethokem have been successfully used with a variety of other herbicides to enhance their efficacy (1, 13, 21, 22).

Table 2. Damage scores and dry matter yield for *P. distichum* treated with nicosulfuron and various adjuvants.

| Treatment | Rate (g a.i./ha) | Adjuvant | Rate | Percent damage (16 d.a.t.) | Percent damage (28 d.a.t.) | Dry matter (g/pot) |
|---|---|---|---|---|---|---|
| Nicosulfuron | 80 | - | | 67 | 79 | 3.57 |
| Nicosulfuron | 160 | - | | 67 | 81 | 1.51 |
| Nicosulfuron | 80 | Ethokem | 1 L/ha | 78 | 92 | 0.64 |
| Nicosulfuron | 80 | Ethokem | 2 L/ha | 78 | 93 | 0.50 |
| Nicosulfuron | 80 | Weed Master | 0.25% | 73 | 80 | 2.33 |
| Nicosulfuron | 80 | Weed Master | 0.50% | 76 | 82 | 0.83 |
| Nicosulfuron | 80 | Uptake | 0.25% | 74 | 88 | 2.90 |
| Nicosulfuron | 80 | Uptake | 0.50% | 74 | 86 | 2.45 |
| Nicosulfuron | 80 | Shell oil | 0.25% | 70 | 77 | 4.95 |
| Nicosulfuron | 80 | Shell oil | 0.50% | 68 | 78 | 4.56 |
| Nicosulfuron | 80 | Frigate | 0.50% | 88 | 94 | 0.16 |
| Nicosulfuron | 80 | Frigate | 1.0% | 92 | 96 | 0.09 |
| Nicosulfuron | 80 | Armoblen | 0.075% | 71 | 75 | 4.91 |
| Nicosulfuron | 80 | Armoblen | 0.15% | 76 | 80 | 1.42 |
| Untreated | - | - | - | 0 | 0 | 28.94 |
| l.s.d. (P= 0.05) | | | | 6 | 8 | 1.05 |

The most commonly reported adjuvants to be used with nicosulfuron appear to be non-ionic surfactants and concentrated crop oils (mainly mineral oil derivatives) probably because these are the adjuvants recommended by Du Pont in the U.S.A (2). For example, when evaluating nicosulfuron for control of the perennial grass weed wirestem muhly (*Muhlenbergia frondosa* (Poir) Fern) in maize, Nandula *et al* (18) included a non-ionic surfactant, both crop oil and vegetable oil concentrates and an organosilicone surfactant. They found that the vegetable oil concentrate was the most effective while the non-ionic surfactant was the least effective in improving herbicide efficacy. In contrast, Kapusta *et al* (12) found that both a mineral oil and a non-ionic surfactant dramatically increased the efficacy of nicosulfuron on a range of annual grass and broad-leaved weeds in maize. Nalewaja et al (17) evaluated 17 non-ionic surfactants for use with nicosulfuron on yellow foxtail (*Setaria glauca* (L.) Beauv.). These adjuvants resulted in fresh weight reductions ranging from 10-90%. Most of the effective adjuvants had a hydrophilic-lipophilic-balance (HLB) above 13 and the authors suggested this should be used as a guide when choosing adjuvants for use with nicosulfuron. However, among the best adjuvants was one with a very low HLB, and also information on HLB is not readily available for many of the adjuvants available outside the USA.

Table 3. Damage scores and dry matter yields of maize treated with nicosulfuron and various adjuvants.

| Treatment | Rate (g a.i./ha) | Adjuvant | Rate | Percent damage (4 d.a.t.) | Percent damage (11 d.a.t.) | Dry matter (g/pot) |
|---|---|---|---|---|---|---|
| Nicosulfuron | 80 | - | | 0.7 | 1.3 | 5.05 |
| Nicosulfuron | 160 | - | | 1.3 | 3.9 | 5.39 |
| Nicosulfuron | 80 | Ethokem | 1 L/ha | 4.6 | 5.6 | 5.00 |
| Nicosulfuron | 80 | Ethokem | 2 L/ha | 5.2 | 5.6 | 5.40 |
| Nicosulfuron | 80 | Weed Master | 0.25% | 2.7 | 4.8 | 4.82 |
| Nicosulfuron | 80 | Weed Master | 0.50% | 3.2 | 7.1 | 4.90 |
| Nicosulfuron | 80 | Uptake | 0.25% | 1.5 | 3.0 | 5.12 |
| Nicosulfuron | 80 | Uptake | 0.50% | 1.5 | 3.8 | 5.16 |
| Nicosulfuron | 80 | Shell oil | 0.25% | 0 | 0.9 | 5.47 |
| Nicosulfuron | 80 | Shell oil | 0.50% | 1.5 | 2.9 | 4.76 |
| Nicosulfuron | 80 | Frigate | 0.50% | 4.5 | 3.5 | 4.36 |
| Nicosulfuron | 80 | Frigate | 1.0% | 5.8 | 5.8 | 4.77 |
| Nicosulfuron | 80 | Armoblen | 0.075% | 2 | 2.6 | 4.96 |
| Nicosulfuron | 80 | Armoblen | 0.15% | 2 | 2.6 | 4.83 |
| Untreated | - | - | - | 0 | 0 | 5.51 |
| l.s.d. (P= 0.05) | | | | 1.7 | 1.8 | 0.57 |

The results presented in Table 3 show that some adjuvants significantly reduced the tolerance of maize to nicosulfuron. Ethokem, Weedmaster CT Surfactant, Frigate and Armoblen 650 caused significant early damage to the maize plants. For Ethokem and Frigate, the damage symptoms of discoloration appeared within days of treatment and sometimes a lower growth rate was observed about a week after treatment. The damage to maize was worse in the second experiment compared to the first, probably due to the higher temperatures experienced soon after spraying in Experiment 2 where treatments were applied later in the season. Previous observations have shown that with Ethokem the level of damage appears to be related to air temperature at the time of treatment. As these experiments were conducted in a glasshouse where temperatures were higher than outside, the damage should be less in a field situation. This has been largely confirmed with observations in our field experiments where the damage symptoms have been noted to a lesser degree and do not appear to have any long term or significant effect on the maize crop as the damaged leaves are soon replaced by new, unaffected growth and grain production is normal (11).

The basis of selectivity of nicosulfuron is in its ability to rapidly (i.e. within 24 h) metabolise the active ingredient to inactive forms (6). However with maize, this ability varies with genotype and although the metabolism is rapid, some temporary checking of growth can occur (8, 15, 16). In our experiments the maize plants were harvested within 3 weeks of treatment when the effects on growth were the maximum. Normally the maize plants recover well from these temporary checks and continue to grow normally. The safety of nicosulfuron in maize has been widely reported, and this herbicide is considered to be very safe at rates up to 280 g/ha (14). However, when used in combination with adjuvants this selectivity can be reduced (5). Based on the results of this study and further field observations (11), Ethokem and Frigate appear as the best options for enhancing the efficacy of nicosulfuron on *P. distichum*, without appreciably reducing crop tolerance.

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# INCREASED EFFICACY AND HIGH SELECTIVITY WITH A NEW FORMULATION OF CYHALOFOP-BUTYL READY MIXED WITH PG26-2 IN JAPAN

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*Summary*: A new formulation, cyhalofop-butyl 5% emusifiable concentrate (EC) ready mixed with 40% polyglycol 26-2 (an alkyl phenolic glycol ether, PG26-2), showed complete control of barnyard grass (*Echinochloa crus-galli*, ECHCG) up to 7-leaf stage with foliar spray at the rate of 200 g a.i./ha in the field. The formulation showed better efficacy with lower rate than a current commercial product, Clincher EW (cyhalofop-butyl 30% emulsion oil in water, EW), because PG26-2 enhanced efficacy. Field and greenhouse studies under conditions of different temperature and different soil moisture showed that the new formulation gave very stable efficacy under various conditions. Also this formulation showed no serious visual injury and no deleterious effect on growth and yield of transplanted rice.
Cyhalofop-butyl : (R)-butyl 2-(4-(4-cyano-2- fluorophenoxy)phenoxy) propionate

*Keywords*: cyhalofop-butyl, PG26-2, barnyard grass, *Echinochloa crus-galli.*

## INTRODUCTION

The 4-(aryloxy)phenoxypropanoates were developed for selective control of grass weeds in crops and have been extensively used for post-emergence control of annual and perennial grass weeds in broad-leaved crops such as soybean, cotton, sugar beet and others. Their herbicidal activity is due to selective inhibition of the acetyl-CoA carboxylase in grasses, a primary enzyme in fatty acid biosynthesis (1).

A wide variety of molecules in this group have been developed so far, but only cyhalofop-butyl is registered for controlling weeds in rice in Japan. Cyhalofop-butyl is the first molecule in this group that can be used in rice for control of barnyard grass both as a foliar spray and granule. This molecule shows sharp inter-generic selectivity between *Oryza* spp. and *Echinochloa* spp. This selectivity is due to the fact that rice metabolizes this molecule to the biologically inactive di-acid more rapidly than barnyard grass (2).

In Japan, a 30% EW formulation of cyhalofop-butyl was registered in April, 1996. This formulation has shown excellent control against barnyard grass up to 5-leaf stage with foliar application in a paddy field without any phytotoxicity against transplanted and direct-seeded rice. Moreover it has been found that PG26-2 enhanced efficacy of cyhalofop-butyl against barnyard grass either as tank-mix or ready-mix. Development of cyhalofop-butyl 5% EC ready mixed with 40% PG26-2 started in 1996 in Japan. In the present study, efficacy of the formulation against barnyard grass under various conditions in the field and in the greenhouse, and growth and yield of rice after treatment are described.

Properties of the new formulation, cyhalofop-butyl 5% EC ready mixed with 40% PG26-2
Appearance: Light yellow liquid; Odor: Less odor conventional Ecs; Stability: Stable at 50 for 3 months; Flash point: High (140).

## MATERIALS AND METHODS

The formulations used in the present study were the new formulation, cyhalofop-butyl 5% (w/w) EC ready mixed with 40% (w/w) PG26-2, and cyhalofop-butyl 30% (w/w) EW.

*Field trial 1*: A field trial for testing the efficacy of cyhalofop-butyl against different leaf stages of barnyard grass was conducted at Fukuoka, Japan in 1996. The trial was designed in a randomized complete block layout with 3 replications. Plot size was 2x2 m. Japonica rice (*Oryza sativa*, ORYSA) at 2.5 leaf stage was transplanted 3 cm deep by machine at the rate of 20 hills/m². Barnyard grass germinating spontaneously was used. Formulations were foliar-sprayed on transplanted rice at 4.5 and 5.5-leaf stages and barnyard grass at 5, 6 and 7-leaf stages. Rates were 200 and 250 g a.i./ha for the new formulation and 200, 250 and 300 g a.i./ha for cyhalofop-butyl 30 % EW. The spray volume was 1000 L/ha. Water was drained at application. Efficacy and injury rating were conducted by visual percent, 0 to 100 % at 15 days after application.

*Field trial 2*: A field trial on growth and yield of rice treated with cyhalofop-butyl at the double use rate was conducted in the same manner in terms of plot design, plant preparation, spray volume and water management as in field trial 1. Bifenox at 1050 g a.i./ha was treated in all plots at the day of rice transplanting. The formulations were foliar-sprayed on 5.8-leaf stage rice and 5-leaf stage barnyard grass. Rates were 500 g a.i./ha for the new formulation and 600 g a.i./ha for cyhalofop-butyl 30% EW. Growth and yield of rice were assessed by measuring rice plant height, the number of stems per hill and total weight of grains per plot at 2 months after rice transplanting (34 days after application).

*Field trial 3*: Field trials under different temperature regimes were conducted 3 times from April to July to evaluate the variance due to temperature on efficacy of the new formulation. Plot design, plant preparation, spray volume and water management were the same as in field trials 1 and 2. The sizes of rice and barnyard grass at application timing were 5.5 and 6-leaf stage respectively. The rate was 250 g a.i./ha. Assessment was made at 20 days after application.

*Greenhouse trial*: A greenhouse study with pots was conducted in 1996. Stainless steel pots, 0.14x0.24 m, were filled with puddled soil and barnyard grass was seeded and grown to desire leaf stages. The pots were flooded with 3 cm water depth until 5 days before application, and then water was drained. For a study of wet soil (drained condition), soil was maintained under water saturated condition, and for a drought study, soil was allowed to dry with minimum water supply until study completion, where plants were exposed to high moisture stress. The formulations were foliar-sprayed on 5-leaf stage barnyard grass at 100, 200 and 300 g a.i./ha. Spray volume was 1000 L/ha. Assessment was made at 28 days after application by visual % control.

## RESULTS AND DISCUSSION

*Efficacy and injury with the new formulation of cyhalofop-butyl (Field trial 1)*: The new formulation, cyhalofop-butyl ready mixed with PG26-2, provided complete control against 5, 6 and 7-leaf stage barnyard grass at 200 and 250 g a.i./ha. Cyhalofop-butyl 30% EW showed excellent control against 5-leaf stage barnyard grass at 250 and 300 g a.i./ha (label use rate is 300 g a.i./ha for control of 5-leaf stage barnyard grass), but not excellent (95%) control against 6-7 leaf stage barnyard grass. Significantly greater efficacy was observed with the new formulation in comparison with cyhalofop-butyl 30% EW. It appears that accelerated uptake of cyhalofop-butyl caused by PG26-2 led to this enhancement of efficacy (3). Neither formulation caused any serious injury (Table 1).

Table 1. Efficacy and injury with the new formulation against 5 to 7 leaf stage barnyard grass and 4.5 and 5.5 leaf stage rice compared with cyhalofop-butyl 30% EW in the field

| Treatment | Rate | Control of ECHCG (%) | | | Injury of ORYSA (%) | |
|---|---|---|---|---|---|---|
| | g a.i./ha | 5 Lf | 6 Lf | 7 Lf | 4.5 Lf | 5.5 Lf |
| Cyhalofop-butyl | 250 | 100 | 100 | 100 | 0 | 0 |
| 5% EC | 200 | 100 | 100 | 100 | 0 | 5 |
| 40% PG26-2 | | | | | | |
| Cyhalofop-butyl | 300 | 100 | 93 | 73 | 0 | 0 |
| 30% EW | 250 | 98 | 85 | 70 | 5 | 0 |
| | 200 | 93 | 66 | 55 | 0 | 0 |

Assessment was made at 15 days after application.
Figures represent the means of 3 replications

*Growth and yield of rice treated with the new formulation of cyhalofop-butyl (Field trial 2)*: Neither the new formulation nor the current product at the double use rate showed any serious adverse effect on growth factors and yield of total grain weight (Table 2). From the results in field trial 1 and 2, it was found that the new formulation showed extremely high efficacy against large barnyard grass up to 7-leaf stage with complete selectivity. The new formulation can provide farmers with great flexibility in application schedule compared to current rice herbicide practices.

Table 2. Growth and yield of transplanted 5.8-leaf stage rice treated with the new formulation at the double use rate (500 g a.i./ha) compared with cyhalofop-butyl 30% EW at the double use rate (600 g a.i./ha).

| Treatment | Rate (g a.i./ha) | Height | Stems/hill | % against hand-weeding [1]Weight of grains/plot | |
|---|---|---|---|---|---|
| Cyhalofop-butyl 5% EC %PG26-2 | 500 | 97.9 | 102.3 | 98.5 | 40 |
| Cyhalofop-butyl 30% EW | 600 | 98.8 | 98.3 | 101.2 | |
| [2]Untreated | | 92.0 | 79.6 | 59.8 | |
| Hand-weeding (No weeds) | | 100 | 100 | 100 | |

Assessment was made at 34 days after application
Figures represent the means of 3 replications.
Bifenox at 1050 g a.i./ha was treated in all plots at the day of rice transplanting.
1 Percent of rough rice yield compared to hand-weeding
2 Untreated with cyhalofop-butyl but treated with bifenox

*Efficacy of the new formulation of cyhalofop-butyl under different temperature condition (Field trial 3)*: Efficacy of the new formulation against 6 leaf stage barnyard grass was stable across temperature regimes. The range of temperatures tested here covered almost all possible temperatures for 6 leaf stage barnyard grass application timings in Japan (Table 3). We concluded that the new formulation provided very consistent efficacy against higher leaf stage barnyard grass across the range of temperatures found in Japan.

Table 3. Efficacy against 6-Lf barnyard grass and injury against 5.5-Lf transplanted rice treated with the new formulation under the condition of different temperature in the field

| Treatment | Rate | % visual control 6-Lf ECHCG [1]Temp.1 | Temp.2 | Temp.3 | | % visual injury 5.5-Lf ORYSA Temp.1 | Temp.2 | Temp.3 |
|---|---|---|---|---|---|---|---|---|
| Cyhalofop-butyl 5% EC 40% PG26-2 at 250 g a.i./ha | 100 | 98 | 98 | | 5 | 0 | 0 | |

Assessment was made at 20 days after application.
Figures represent the means of 3 replications.
1 Temp.1: Mean 15.5, max. 27.2, min. 8.4 during 2 weeks after application
Temp.2 : Mean 23.6, max. 28.1, min. 15.3 during 2 weeks after application
Temp.3 : Mean 28.5, max. 35.9, min. 22.7 during 2 weeks after application

*Influence of drought condition on efficacy of the new formulation of cyhalofop-butyl (Greenhouse trial)*: Reduced activity of other selective post-emergence grass herbicides under moisture stress have been reported in both the field and greenhouse (4). Cyhalofop-butyl 30% EW showed the same trend as other grass herbicides, and reduced efficacy was observed against 5 leaf stage barnyard grass in drought condition in comparison to wet soil (water saturated) condition. However, no reduced efficacy was observed for the new formulation against 5 leaf stage barnyard grass under high moisture stress (Table 4). We concluded from this study and from field trial 3 that the new formulation was very stable in efficacy under various environmental conditions.

*Conclusion*: The new formulation showed excellent control of up to 7-leaf stage barnyard grass without any reduction in crop safety at a lower rate (200 g a.i./ha) than cyhalofop-butyl 30% EW, which required 250 g a.i./ha to control 5-leaf stage barnyard grass. Moreover, it was found that the efficacy of the new formulation was very stable under various environmental conditions. Clearly, this new formulation can provide farmers with reliable weed control and great flexibility in terms of application schedule.

Table 4. Influence of drought condition on efficacy of the new formulation compared with cyhalofop-butyl 30% EW against 5-Lf barnyard grass under greenhouse condition

| Treatment | Water condition | Rate g a.i./ha | % visual contr 5-Lf ECHCG |
|---|---|---|---|
| | | 300 | 100 |
| | Drought | 200 | 98 |
| Cyhalofop-butyl | | 100 | 95 |
| 5% EC | | | |
| 40% PG26-2 | | 300 | 100 |
| | Wet | 200 | 100 |
| | | 100 | 98 |
| | | 300 | 75 |
| | Drought | 200 | 73 |
| | | 100 | 55 |
| Cyhalofop-butyl | | | |
| 30% EW | | 300 | 100 |
| | Wet | 200 | 98 |
| | | 100 | 83 |

Assessment was made at 28 days after application.
Figures represent the means of 3 replications.

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# EFFECT OF CARRIER VOLUME AND ORGANO-SILICON SURFACTANT ON METSULFURON-METHYL EFFICACY AGAINST *DIODIA OCIMIFOLIA*

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*Summary*: The effects of carrier volume and surfactant on the efficacy of metsulfuron-methyl for the control of *Diodia ocimifolia* were evaluated in the glasshouse. Visual assessment and weed fresh weight data showed that the presence of organo-silicon surfactant (PULSE) at 0.25% v/v enhanced the efficacy of metsulfuron-methyl against *D. ocimifolia.* This is due to increased spray solution retention on the leaf surface. Reducing carrier volume from 600 to 200 L/ha improved the effectiveness of metsulfuron-methyl. Nevertheless, the effect of surfactant is not significant at carrier volume less than 200 L/ha. At 400 and 600 L/ha carrier volume, the surfactant significantly enhanced the efficacy of metsulfuron-methyl against *D. ocimifolia.*

*Keywords*: metsulfuron-methyl, spray retention, *Diodia ocimifolia,* fluorescent tracer technique, organo-silicon surfactant.

## INTRODUCTION

*Diodia ocimifolia* is one of the noxious perennial weeds fast assuming importance in recent years in Malaysian plantations. The potential for greater spread and dominance is evident, given its high seeding capacity and density. Presently, herbicides is the only means of control. Metsulfuron-methyl (ALLY®) alone or tank mixtures with other herbicides such as paraquat and glyphosate were effective for the control of this weed (3, 7). Metsulfuron-methyl is a sulfonylurea herbicide for broad-spectrum post-emergence broad-leaved weed control. An important feature of this compound is its herbicidal activity at extremely low application rates; 10 and 15 g ai/ha for general weed control; 30 g ai/ha for woody brush control in plantation crops.

A number of reports showed significant improvement in herbicide efficacy as the carrier volume decreased (6, 9). Reducing the carrier volume does not generally affect the mode of action of herbicide, but improve the amount retained on the plant and thus the amount available for penetration. Mean droplet size may also be reduced because nozzles with smaller orifices are generally used. The resulting smaller spray droplets improve spray contact and coverage (2). Surfactants are commonly used with post-emergence herbicides to enhance their performance by promoting penetration of the active ingredient through the leaf cuticle to the points of biological action in the epidermal and mesophyll cells. (4). Surfactants also affected the behavior of both spray deposition on difficult-to-wet leaf surfaces (1) and spray retention (10). This could be particularly important at higher carrier volume application when the spray solution retained on the leaf is near saturation capacity and spray solution run-off could be exacerbated by the presence of surfactant. However, the effects of reducing the carrier volume and adding surfactant for the control of *D. ocimifolia* was not really understand even though there has been a major shift from high volume (HV) application towards very low volume (ULV) and ultra low volume (ULV) applications.

The objective of this study was to determine the influence of carrier volume and surfactant on the effectiveness of metsulfuron-methyl on *Diodia ocimifolia* under glasshouse conditions.

## MATERIALS AND METHODS

*Diodia ocimifolia* seeds collected from an oil palm plantation in Selangor were cleaned, air-dried and stored in a refrigerator before sowing. The seeds were sown in 38x28 cm trays containing mixture of sand and top soil at a ratio of 2:1. Two weeks after germination, seedlings were transplanted in 2-litre pots containing the same potting mixture with 1 plant per pot. Watering was carried out twice daily and compound fertilizer (15% N, 15% P and 15% K) was applied when necessary. Uniform and vigorous *D. ocimifolia* seedlings at 20-30 cm height (6 weeks after transplanting) were selected for treatment. The experiment was set up using a split-plot design with surfactant as main factor and carrier volume as a sub-plot. Each treatment was replicated four times. All data were subjected to analysis of variance and treatment means were compared using Tukey's Test.

*Effect of carrier volume and surfactant on the efficacy of metsulfuron-methyl against D. ocimifolia*: The 8-week old plants were foliar sprayed at 30 g ai/ha of metsulfuron-methyl (ALLY® 20EDF). Spraying was carried out using a knapsack sprayer (PB Crossmark) fitted with TeeJet XR11001 (orange), XR11002 (yellow), XR11006 (grey) and XR11008 (white) flat-fan nozzles. The spray volume, pressure and droplet size of the nozzles were calibrated and set as indicated in Table 1. Application of treatments was conducted in the absence and presence of organo-silicon surfactant (PULSE®) at 0.25% v/v.

Table 1: Spray parameters set for this study

| Nozzle Number | Pressure (bar) | Spray Volume (L/ha) | *Droplet Size (Dv) |
|---|---|---|---|
| 1. XR 11001 | 3 | 100 | Fine (170) |
| 2. XR 11002 | 2 | 200 | Medium (243) |
| 3. XR 11006 | 1 | 400 | Coarse (396) |
| 4. XR 11008 | 1 | 600 | Very Coarse (443) |

* Source : Teejet Agricultural Spray Product Manual

The effects of treatments on *D. ocimifolia* was determined by visual assessment using a scale of 0 to 100% where 0% represents no control and 100% represents total plant death at 21-days-after-spraying (DAS). The plants were then harvested and the above ground fresh weight was determined. Percent control data were transformed to arc-sine values before statistical analysis.

*Spray retention study*: Fluorescent tracer technique (8) was used to measure total herbicide deposits on plant. A solution of 0.01% fluresceine in distilled water was sprayed directly on *D. ocimifolia* seedlings. Spraying was conducted using the same four nozzles as the above study in the absence and presence of organo-silicon surfactant at 0.25% v/v. Four leaves were randomly harvested from each plant immediately after the spray solution dried. The tracer was washed off from the leaves by shaking them in a plastic bag for 30 seconds in 30 ml of 0.005 M sodium hydroxide. A flourimeter was used to measure the concentration of fluoresceine in the solution. The leaf area was measured using a leaf area meter.

## RESULTS AND DISCUSSION

The presence of 0.25% v/v organo-silicon surfactant increased percent weed control and reduced weed fresh weight significantly (Table 2). These results showed that organo-silicon based surfactant enhanced efficacy of metsulfuron-methyl against *D. ocimifolia.* Jansen (5) reported similar results and suggested that organo-silicon surfactant improved the amount of spray solution retained on the plants which become available for absorption by plant tissues. This conclusion is supported by the spray retention data in this study where percent spray retention was significantly higher with the presence of the surfactant (Table 2).

Table 2: The effect of organo-silicon surfactant on percent weed control, weed fresh weight and percent spray retention

| Treatment | Mean Weed Control[1] (%) | Mean Weed Fresh Weight[1] (g) | Mean Spray Retention[1] (%) |
|---|---|---|---|
| 1. 0.25% v/v Surfactant | 82.50 a | 10.83 b | 0.76 a |
| 2. No Surfactant | 76.62 b | 14.10 a | 0.53 b |

[1]Values in the same column having the same letter are not significantly different at p= 0.01

Increasing carrier volume from 200 L/ha to 600 L/ha reduced percent weed control and increased weed fresh weight in the absence and presence of organo-silicon surfactant (Table 3). This indicated that a significant decrease in performance of metsulfuron-methyl on *D. ocimifolia* as the carrier volume increased. Smaller droplet size produced at lower carrier volume has greater surface contact due to a more uniform spray distribution, allowing more metsulfuron-methyl absorption per unit of spray solution retained on the plant surfaces. This finding was supported by the spray retention study where percent spray retention reduced significantly as the carrier volume increased from 100 to 600 L/ha (Table 4).

Table 3: The effect of carrier volume and organo-silicon surfactant on percent weed control and weed fresh weight

| Carrier Volume (L/ha) | Mean Weed Control[1] (%) | | Mean Weed Fresh Weight[1] (g) | |
|---|---|---|---|---|
| | 0.25% v/v Surfactant | No Surfactant | 0.25% v/v Surfactant | No Surfactant |
| 1. 100 | 85.00 b | 82.00 b | 8.63 c | 9.75 c |
| 2. 200 | 97.50 a | 93.70 a | 5.14 d | 5.80 d |
| 3. 400 | 73.85 c | 63.70 d | 11.99 c | 16.98 b |
| 4. 600 | 68.00 d | 48.80 e | 17.57 b | 23.88 a |

[1]Values in the same column having the same letter are not significantly different at $p = 0.01$

Carrier volume also affects the loss of herbicide through run-off from plant surfaces. Results from this study did not indicate an overall loss in *D. ocimifolia* control for carrier volume less that 200 L/ha in the absence or presence of organo-silicon surfactant. The data suggested that carrier volume at 200 L/ha is the saturation capacity of spray solution retained at the plant surfaces. This conclusion is confirmed by the spray retention data which showed that the percent spray retention was not significantly different at carrier volume below 200 L/ha irrespective of the presence of surfactant (Table 4).

Further increase in carrier volume will cause spray solution to run-off and this could be exacerbated by the presence of surfactant. This explanation was supported by the weed control and weed fresh weight data in this study (Table 3). At higher carrier volume of 400 and 600 L/ha the presence of 0.25% v/v organo-silicon surfactant increased weed control and weed fresh weight significantly. With lower herbicide concentration per droplet at higher carrier volume, less herbicide would be absorbed for each unit of spray solution retained on the plant surfaces. The results are in agreement with the hypothesis of Smeda and Putnam (9), who suggested that surfactant enhanced herbicidal activity only when the herbicide available for absorption by plant tissue was limiting.

Table 4: The effect of carrier volume and organo-silicon surfactant on percent spray retention

| Carrier Volume (L/Ha) | Mean Spray Retention[1] (%) | |
|---|---|---|
| | 0.25% v/v Surfactant | No Surfactant |
| 1. 100 | 1.04 a | 1.06 a |
| 2. 200 | 0.99 a | 0.98 a |
| 3. 400 | 0.66 b | 0.29 cd |
| 4. 600 | 0.37 c | 0.17 d |

[1]Values in the same column having the same letter are not significantly different at $p = 0.01$

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# THE ROLE OF SELECTED NON-IONIC SURFACTANTS ON THE UPTAKE AND TRANSLOCATION OF ASULAM APPLIED TO BRACKEN

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*Summary*: The effect of non-ionic nonylphenol (NP) surfactants containing 4-14 ethylene oxide (EO) molecules on the distribution of asulam (log Kow 0.3) was investigated in bracken (*Pteridium aquilium* L. Kuhn). The distribution of the herbicide was dependent on the EO content and concentration of surfactant. The greatest reductions in contact angle, surface tension and greatest droplet diameter were obtained with EO 6.5-10 (at 0.001 to 0.1%). Similarly, surfactants of EO 6.5-10 increased the uptake and translocation of [$^{14}$C]-asulam, particularly at surfactant concentration of 0.01 and 0.1%. These results are discussed with particular reference to a predictive model which offers considerable potential for optimising the performance of formulations.

*Keywords*: bracken, non-ionic surfactants, uptake-translocation

## INTRODUCTION

The control of difficult perennial weeds such as bracken (Pteridium aquilinium L. Kuhn) using systemic herbicides depends upon the efficiency of delivery and action at the target sites, i.e. the rhizome apices and frond buds on the underground rhizome system. The plant cuticle presents a barrier to the penetration of foliage-applied herbicides, particularly due to the epicuticular and cuticular lipids which form the outer regions of the cuticular membrane. The rate of penetration of a systemic polar herbicide such as asulam (log Kow 0.3), can be greatly increased by the use of certain surfactants which can influence surface phenomena, cuticle penetration, membrane permeability and indirectly translocation of the active ingredient (a.i.) (5, 6, 7). Synergy may depend on a range of factors including herbicide polarity, surfactant type, hydrophilic-lipophilic balance (HLB) and critical micelle concentration (CMC).

In this paper, the results of studies on the influence of a range of non-ionic polyoxyethylene surfactants of varying ethylene oxide (EO) content will be presented with reference to the effects on the surface properties and uptake-translocation characteristics of $^{14}$C asulam applied to bracken. Effects on activity of asulam were carried out but the results are not presented.

## MATERIALS AND METHODS

The herbicide asulam (methyl-4-aminophenysulphonylcarbamate) was supplied by Rhône Poulenc Agriculture in the technical, formulated and [$^{14}$C] labelled forms; the [$^{14}$C]-ring labelled asulam (sodium salt) had a specific activity of 2.01 MBq/mg. The relative solubilities of asulam in water and acetone were 4g/L and 300g/L respectively and its log Kow was 0.3. The surfactants used were all commercially available nonionics ranging from slightly water soluble (EO4) and dispersible liquids (EO 5.5) to water soluble (high EO); the range of surfactants together with their mean EO number, molecular weight (MW) and hydrophilic-lipophilic balance (HLB) are shown in Table 1.

*Measurement of contact angle and droplet diameter*: The contact angle of 0.5 µl droplets applied to waxed coverslips was measured using a Goniometer telemicroscope on a flat stage. In the case of bracken frond surfaces droplet diameters were measured. The data are not presented.

*Measurement of uptake and translocation*: Model explants were prepared by removing pinnae from the base of uniform mature bracken fronds and the stem of each explant inserted into a vial containing 8 ml of distilled water; the three basal pairs of bracken pinnules were covered with aluminium foil to induce 'sink' activity. Prior to treatment the explants were placed for 24 h in a growth cabinet at 22$^0$C (± 5$^0$C) and 75% (± 5%) relative humidity. ($^{14}$C) Asulam, formulated with surfactants EO 4-14 (0.005%), was applied as 8x0.5 µl (= 4µl) droplets using a Hamilton microsyringe on the middle three pairs of the pinnule segments, there being 4 replicates per treatment; no-surfactant controls were also prepared. The treated explants were replaced in the growth cabinet.

Table 1. Ethylene oxide surfactants, properties and sources

| Surfactant. | EO No | HLB | Mol. Wt. | Manufacturer |
|---|---|---|---|---|
| Ethylan 44 | 4 | 9.0 | 396 | Harcros Chemicals |
| Ethylan 55 | 5.5 | 10.5 | 462 | Harcros Chemicals |
| Ethylan 77 | 6.5 | 10.9 | 484 | Harcros Chemicals |
| Ethylan TU | 8 | 12.3 | 572 | Harcros Chemicals |
| Synperonic-NP10 | 10 | 13.5 | 660 | ICI |
| Ethylan DP12 | 12 | 14 | 748 | Harcros Chemicals |
| Lutensol-AP14 | 14 | 14.5 | 836 | BASF |

Forty-eight hours after treatment, the treated tissue was washed in water (2 ml; 2 min) to remove any surface residues of the [$^{14}$C]-herbicide and thereafter in chloroform (2 ml; 30s) to remove herbicide residues occurring in the epicuticular waxes; the residues from these washes were radio-assayed (data not presented).

The data was subjected to analysis of variance and, where relevant, to Newman-keuls Range test.

## RESULTS AND DISCUSSION

*Droplet properties*: Incorporation of surfactant reduced surface tension (data not presented) and contact angle and increased droplet diameter on the waxy frond surfaces. Surfactants of lower EO numbers were particularly effective; optimum effects occurring with surfactants of mean EO 6-8.

*Uptake and translocation*: The influence of surfactant EO number on the distribution of $^{14}$C-asulam applied to the pinnules of glasshouse-grown bracken is shown in Table 2.

Table 2. The effect of surfactant EO content on the distribution of $^{14}$C-asulam applied to the pinnules of bracken

| Conc. (%) | $^{14}$C-distribution (% of applied) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| EO No. | 0 | 0.005 | 0.01 | 0.1 | 0 | 0.005 | 0.01 | 0.1 |
| Uptake | | | | | Translocation | | | |
| 4 | 22.73a | a53.30ab | a56.12ab | 66.68 | 4.37a | a6.62ab | a7.73a | 10.58a |
| 6.5 | 29.24a | 56.36abc | 79.37b | 93.46b | a7.35ab | a7.68ab | a9.24a | 14.03ab |
| 8 | 29.65a | 60.25bc | a80.43b | a88.39b | a6.76ab | a8.19ab | a10.68a | 16.74b |
| 10 | 32.00a | a74.66c | a75.63ab | a82.42b | a6.38ab | ba10.58b | b14.21a | ba11.18a |
| 14 | a31.99a | b61.52bc | b55.79ab | a37.37a | b8.93b | a4.14a | ba6.08a | ba6.17 |
| †Adder | a31.43a | a38.25a | a49.64a | a45.55a | a8.22b | a8.00ab | a17.67a | a9.57a |

*In this and other tables, where relevant, means within a row with common prescripts and in a column with common postscripts do not differ significantly at P=0.05, †Rhône-Poulenc formulant

Uptake and translocation increased with surfactant concentration, particularly in the case of surfactants EO 6.5 to 8. Similar trends were obtained when $^{14}$C asulam was applied to field grown bracken (data not presented). The effect of treatments on translocation per se, was determined by calculating translocation of $^{14}$C asulam as a % of the absorbed dose (Table 3). Treatment of data for glasshouse-grown pinnae indicate that surfactants have little direct effect on translocation, whereas, in field grown plants the efficiency of translocation was enhanced, especially by surfactants of EO 6.5-8 (0.1%.).

The properties of the plant cuticle have been reviewed by several authors, including Holloway (2), Baker (1), Price (8), Tadros (11) and Kirkwood (4). Permeability of the cuticular membrane (i.e. cutin and cuticular waxes) is largely due to the wax component of the cuticle and is influenced by cuticle thickness, wax viscosity and structure, molecular radius of the a.i., partition coefficient of the a.i., effective area, formulation and temperature. The finding that certain surfactants can enter the plant tissues (9) via cuticle penetration pointed to the possibilities of 1) surfactant-induced predisposition of the cuticle to penetration of an a.i. (pre-penetration), or 2) co-penetration of surfactant and a.i. (3).

Table 3. The effect of surfactant mean EO content on the translocation of $^{14}C$-asulam in bracken explants from glasshouse (A) or field grown (B, C) bracken

| Conc. (%) | | Translocation (% absorbed) | | | |
|---|---|---|---|---|---|
| EO No | | Control | 0.005 | 0.01 | 0.1 |
| A. | 4 | 20.28 | 12.95 | 14.05 | 15.88 |
| | 6.5 | 25.00 | 13.61 | 11.59 | 15.01 |
| | 8 | 22.72 | 13.48 | 12.80 | 18.93 |
| | 10 | 20.79 | 14.52 | 18.66 | 13.58 |
| | 14 | 27.74 | 06.65 | 10.78 | 17.37 |
| | †Adder | 25.88 | 21.55 | 35.96 | 20.59 |
| B* | 4 | 20.89 | --- | 34.84 | 47.59 |
| | 6.5 | 6.73 | --- | 38.76 | 72.25 |
| | 8 | 3.94 | --- | 48.66 | 52.56 |
| | 10 | 5.00 | --- | 32.29 | 37.43 |
| | 14 | 13.26 | --- | 25.83 | 25.73 |
| | †Adder | 12.41 | --- | 21.44 | 15.80 |
| C | 4 | 7.82 | --- | 20.79 | 43.31 |
| | 6.5 | 10.66 | --- | 29.89 | 47.91 |
| | 8 | 13.20 | --- | 36.19 | 39.70 |
| | 10 | 11.57 | --- | 27.42 | 42.35 |
| | 14 | 4.77 | --- | 39.04 | 31.23 |
| | †Adder | 7.55 | --- | 14.46 | 22.94 |

* B=Stage I
C=Stage II
†Rhône-Poulenc formulant

These authors proposed a predictive model which appear to offer considerable potential for optimising the performance of formulations. Optimum promotion of compounds (like asulam) with low log P (or low log Kow) occurred with surfactants of relatively high EO content while compounds with high log P (lipophilic a.i.) required surfactants of low EO content. Results presented elsewhere showed that optimal surface properties, uptake and translocation of diflufenican (log Kow 4.6) in bracken occurred with a NP surfactant having a mean EO number of 4 which is consistent with the model.

In addition to EO chain length, the beneficial action of the test surfactants was influenced by their concentration. Concentration effects are related to the critical micelle concentration (CMC); at this concentration the physical properties of a surfactant may alter radically. At concentrations above the CMC, surfactants may stabilise the cuticle waxes enhancing cuticle penetration and leaf absorption. In the present studies the beneficial effects of the test surfactants may have involved some interaction with the cuticle waxes, since the concentration range spanned the CMC and above.

In conclusion, the results presented in this paper contribute to the substantial evidence from the literature that appropriate combinations of herbicides with adjuvants can greatly enhance the rate and efficiency of herbicide delivery at the target sites and thus herbicide activity. In principle, such studies can point the way towards the development of more efficient formulations possibly having lower a.i. contents and enhanced environmental and economic properties.

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# EXPRESSION OF *B. SUBTILIS* PROTOPORPHYRINOGEN OXIDASE GENE LEADS TO INCREASED TOLERANCE TO OXYFLUORFEN IN TRANSGENIC TOBACCO

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*Summary*: The complicated herbicidal mechanism of diphenyl-ether compounds provides various way of evolving resistance in plants. It is generally accepted that the primary target of these photodynamic herbicides is protoporphyrinogen oxidase. In an effort to develop transgenic plants with diphenyl-ether resistance, we introduced protoporphyriongen oxidase gene of *B. subtilis* into tobacco. Based on Northern analysis and leaf-disc analysis, the expression of protoporphyrinogen oxidase gene under CaMV 35S promoter in cytosol generated tolerance to oxyfluorfen in transgenic tobacco plants.

*Keywords*: oxyfluorfen, transgenic tobacco, protoporphyrinogen oxidase

## INTRODUCTION

Certain diphenyl-ether compounds such as oxyfluorfen and acifluorfen can be commonly used as effective herbicides in a variety of crops (1-5). It is generally accepted that the primary target of these photodynamic herbicides is protoporphyrinogen oxidase (EC 1. 3. 3. 4), the last common enzyme in the biosynthesis of heme and chlorophyll (6). The biochemical basis for the herbicidal mechanism is known to be the competitive inhibition of plastid protoporphyrinogen oxidase by diphenyl-ether compounds, thereby protoprophyrinogen IX is accumulated in plastid envelope, released into cytosol, transported to plasma membrane, where it is rapidly converted to protoporphyrin IX by a herbicide-resistant peroxidase-like enzyme or auto-oxidation (7-9). The resulting photodynamic protoporphyrin IX mediates lipid peroxidation and cellular death in the presence of molecular oxygen and light. The complicated herbicidal mechanism of diphenyl-ether compounds provides various ways of evolving resistance in plants. These include 1) reducing uptake of herbicides, and 2) degrading herbicides, protoporphyrinogen IX, or protoporphyrin IX. These types of resistance may be found in natural resistance of some plants (10-12). Alternatively, the third type of specific resistance can be generated by manipulation of protoporphyrinogen oxidase gene. In an effort to develop transgenic plants with diphenyl-ether resistance, we introduced protoporphyrinogen oxidase gene of *B. subtilis* into tobacco. The data presented below indicates that the expression of protoporphyrinogen oxidase gene in cytosol generates tolerance to diphenyl-ether in transgenic tobacco plants. In addition, the observed tolerance mechanism in transgenic tobacco plants is briefly discussed.

## MATERIALS AND METHODS

Oxyfluorfen (95% pure) was a generous gift from Rohm and Haas Korea Co., Ltd. Restriction enzymes and DNA modifying enzymes were from Promega and Sigma. All other reagents were of the highest quality commercially available. Phage DNA was isolated from genomic library of *B. subtilis* (Clontech) by standard procedure. Protoporphyrinogen oxidase was amplified by PCR with primers of 5'-GCCG-AAGC-TTGG-ATCC-ATGA-GTGA-CCGC-AAAA- 3' (N-terminal) and 5'-GCCG-AAGC-TTGG-ATCG-TTTT-AGCT-GAAT-AAAT-3' (C-terminal). The 1.4 kb PCR product was digested with BamHI and inserted in the sense orientation between cauliflower mosaic virus CaMV35S promoter and terminator of the NOS gene of pBI121 (Fig. 1A). Promoter and signal peptide region of chlorophyll a/b binding protein gene was cloned by PCR using primers of 5'-GCCG-AAGC-TTGT-CGTC-AGTT-CGAC-TCAC-3' (N-terminal) and 5'-GCCG-GGAT-CCCT-TCCT-CATG-GTCA-ATG-3' (C-terminal). The PCR product was ligated with protoporphyrinogen oxidase gene of *B. subtitlis* and resulting Cab-promoter/signal sequence-protoporphyrinogen oxidase gene (1.6 kb) substituted CaMV35S-promoter-NOS region of pBI121 vector (Fig. 1B). These constructs were used to transform tobacco leaf segment via *Agrobacterium*. Transgenic plants were screened by PCR and Southern analysis with protoporphyrinogen oxidase gene (1.4kb) as a probe. Transgenic plants containing *B. subtilis* protoporphyrinogen oxidase gene were used for further analysis.

## RESULTS AND DISCUSSION

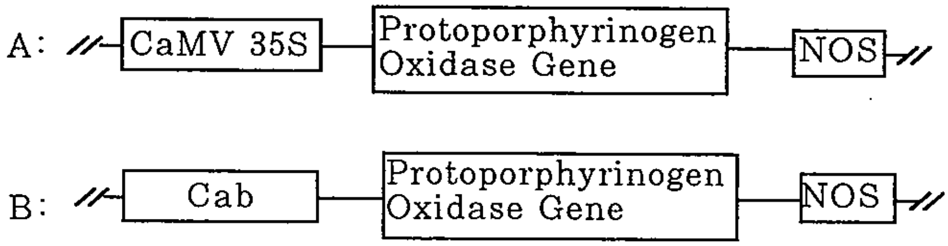


Fig. 1 Structure and Chimeric Protoporphyrinogen Oxidase Gene Construct Used for Transformation of Tobacco Plants. PCR products of protoporphyrinogen oxidase gene from *B. subtilis* was inserted between the CaMV 35S promoter (A) or potato Cab promoter/signal sequence (B) and NOS gene.

It has been shown that protoporphyrinogen oxidases originated from prokaryotes are not inhibited by diphenyl-ether compounds (13, 14). Protoporphyrinogen oxidase from *B. subtilis* has been cloned and expressed in *E. coli* (14). In the current study we have isolated protoporphyrinogen oxidase gene from genomic library of *B. subtilis* by PCR. The PCR

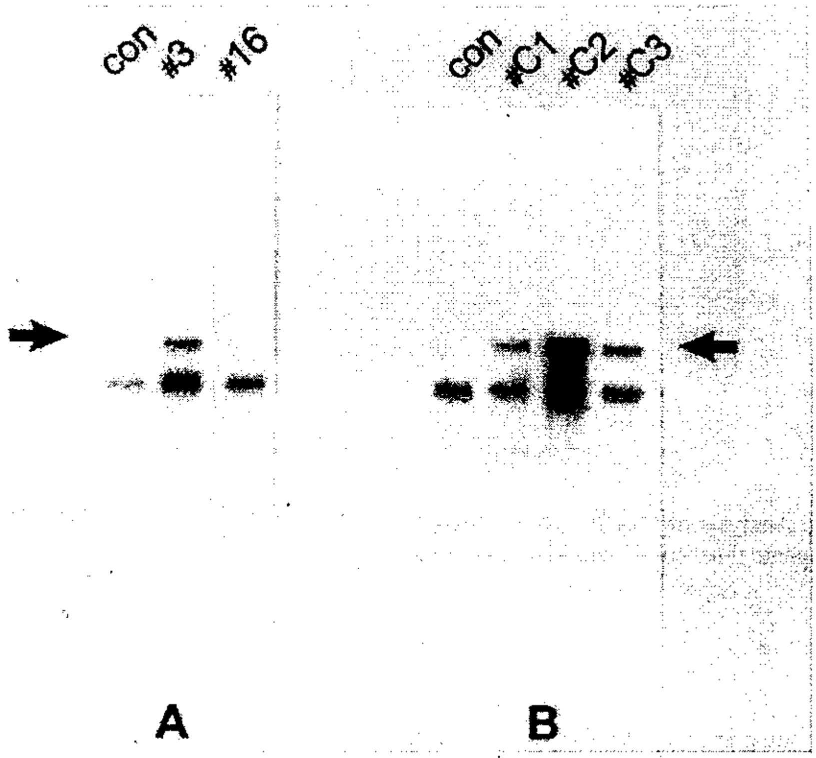


Fig. 2 Northern Analysis of Transgenic Tobacco plant. A: under CaMV 35S promoter, con; nontransgenic tobacco, #3 and #16; transgenic tobacco, B: under Cab promoter/signal sequence, con; nontransgenic tobacco, #C1, #C2, #C3; transgenic tobacco. The arrow indicates transcript of protoporphyrinogen oxidase gene and the lower band is due to Cab protein transcript.

amplified gene was inserted into pBI121 under CaMV 35S promoter be expressed sequence or Cab promoter/singal sequence (Fig. 1). We expected that protoporphyrinogen oxidase gene under CaMV 35S promoter be expressed in cytosol and Cab promoter/signal sequence directs the protein expression of protoporphyrinogen oxidase gene to chloroplast.

Northern analysis with Cab promoter/signal sequence-protoporphyrinogen oxidase gene (1.6 kb) as a probe clearly showed that protoporphyrinogen oxidase gene of *B. subtilis* was expressed in transgenic tobacco as seen in Fig. 2. The expression of transgene was higher in plant #3, C#1, C#2, C#3 than #16. Therefore, the expression level of transgene was reasonaly high in transgenic tobacco under the both cases of CaMV 35S and Cab promoters.

The oxyfluorfen tolerance of transgenic tobacco plants was analyzed by leaf-disc method. As seen in Fig. 3, transgenic tobacco plants under CaMV 35S promoter was resistant at high concentration (0.1mM) of oxyfluorfen and the level of resistance could be correlated to mRNA expression when the transcription level (Fig. 2) was compared with the resistance level (Fig. 3). However, growth rate was significantly low and synthesis of chlorophyll was retarded based on electron microscopic structure of thylakoid memebranes of transgenic tobacco under Cab promoter/signal sequence (data not shown).

In conclusion, the expression of protoporphyrinogen oxidase gene under CaMV35S promoter in cytosol generated tolerance to oxyfluorfen in transgenic tobacco plants. The tolerance mechanism in transgenic tobacco plants might be complicated due to complex action mechanism of diphenyl-ether herbicides. One plausible explanation would be re-utilization of protoporphyrinogen oxidase expressed in cytosol. It has been proposed that protoporphyrin IX in cytosol could be transported to mitochondria and utilized for biosynthesis of heme (15).

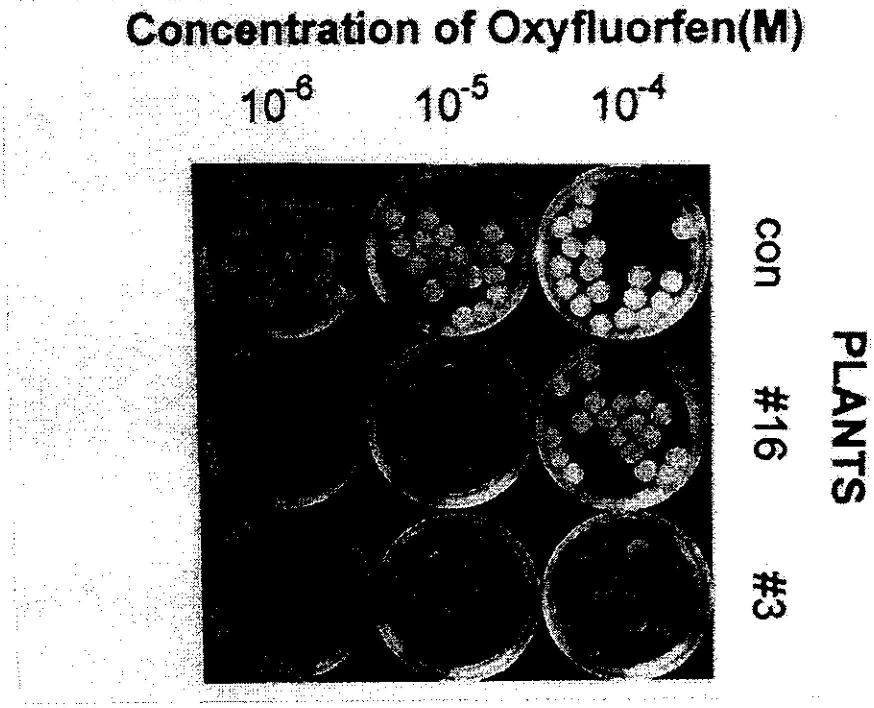


Fig. 3 Leaf-disc Analysis of Oxyfluorfen Resistance in Transgenic Tobacco Plants under CaMV 35S promoter. Con: nontransgenic tobacco, #3 and #16: transgenic tobacco.

ACKNOWLEDGEMENTS

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# MECHANISM OF GLYPHOSATE TOLERANCE IN CELL LINES OF GROUNDNUT

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*Summary*: Glyphosate tolerant cell lines of groundnut (*Arachis hypogaea* L.) show a significant increase in the total extractable activity of the target enzyme, 5-*enol*pyruvylshikimate-3-phosphate (EPSP) synthase (EC 2.5.1.19). Two other key regulated enzymes of the shikimic acid pathway, namely, 3-deoxy-D-arabino heptulosonate 7-phosphate (DAHP) synthase (EC 4.1.2.15) and chorismate mutase (CM) (EC 5.4.99.5) did not show any change in specific activity in the selected cell lines. Nucleic acid analysis revealed amplification of the EPSP synthase genes and enhanced transcript levels. The amplification and expression of EPSP synthase genes was found to be stable in the absence of selection pressure.

*Keywords*: *Arachis hypogaea*, glyphosate tolerance, EPSP synthase

## INTRODUCTION

Groundnut is an important oilseed legume crop in India, occupying first position both in terms of area and production. It occupies about 45% of the total cultivated land and yields about 55% of the oilseed produced. Groundnut is particularly sensitive to losses due to weed competition, primarily because of it's slow growth, short stature, rainfed and pegging habit. These features also make mechanical weeding very difficult. In India, yield losses of groundnut due to weeds may be as high as 88% (1).

Glyphosate [*N*-(phosphonomethyl)glycine] is a non-selective, foliar-applied, post-emergence, systemic herbicide with low mammalian toxicity and is at present the most extensively used herbicide. Glyphosate is a potent inhibitor of the shikimic acid pathway, a site of action unique amongst herbicides. It acts specifically by inhibiting the target enzyme 5-*enol*pyruvylshikimate-3-phosphate (EPSP) synthase (EC 2.5.1.19), culminating in the arrest of protein synthesis and the prevention of secondary metabolism. While tolerance to glyphosate could (presumably) be acquired at the cellular level by it's reduced uptake, degradation or conjugation, the two possible target related mechanisms are particularly informative because they allow firm conclusions with reference to the mode of action of the herbicide. Several microorganisms and plant cell lines selected for glyphosate tolerance have been reported. In cell lines of carrot, tobacco, *Petunia*, *Corydalis*, *Catharanthus*, barley and chicory, glyphosate tolerance has been accorded to overexpression of the glyphosate sensitive form of EPSP synthase. In contrast, herbicide insensitive form of the enzyme has been reported in *Salmonella typhemurium*, *Aerobacter aerogenes*, *Agrobacterium tumefaciens*, *Anabaena variabilis*, *Euglena gracilis* and lately in a maize cell culture line.

In the present investigation, we have attempted isolation of glyphosate tolerant cell lines of *Arachis hypogaea* L. by using *in vitro* culture techniques and conducted investigations to understand the biochemical and molecular mechanism of glyphosate tolerance in *A. hypogaea.*

## MATERIALS AND METHODS

*Biochemicals*: The biochemicals were purchased from Sigma Chemical Co. (St. Louis, MO, USA). The ammonium salt of shikimate-3-phosphate was prepared according to Coggins *et al.* (4). Chorismate was purified following the procedure of Gibson (7). Technical grade glyphosate (isopropylamine salt) was a gift from EPIC, India. The $\alpha^{32}P$ ATP was purchased from BARC, India.

*Selection of glyphosate tolerant cell lines*: Isolation of three glyphosate tolerant cell lines of groundnut *var*. JL 24 has previously been described (11). Whereas GRS1 was derived from a mutagenized suspension culture selected on a lethal dose of the herbicide, GR1 and GR2 were isolated *via* single and multistep selection protocols respectively.

*Enzyme assays*: The procedure of Sharma *et al.* (12) was followed for assaying DAHP synthase and chorismate mutase. The enzyme EPSP synthase was assayed by the procedure of Forlani *et al.* (6) and the activity was corrected for the release of $P_i$ by phosphatases, assayed using *p*-nitrophenylphosphate as the substrate.

*Immunodetection of EPSP synthase*: Immunoreactive EPSP synthase was quantified by ELISA using polyclonal antiserum. Antiserum directed against EPSP synthase was prepared by immunizing rabbit with a purified preparation of the enzyme from *Bacillus subtilis*.

*Protein estimation*: The method of Bradford (2) was followed for protein quantification using BSA as the standard..

*Nucleic acid analysis*: High molecular weight genomic DNA of groundnut was prepared by following the protocol of Walbot (13) originally developed for rice. Total RNA was isolated using TriPure™ Isolation Reagent (Boehringer Mannheim) according to the technical information supplied by the manufacturer. Gel electrophoresis of nucleic acids and subsequent transfer to the nylon membranes (Boehringer Mannheim), and hybridization conditions were essentially according to Maniatis (10). The DNA probes were radiolabelled with $\alpha^{32}P$ using random priming kit from Boehringer Mannheim.

## RESULTS AND DISCUSSION

*Selection of glyphosate tolerant cell lines*: Isolation of glyphosate tolerant cell lines of *Arachis hypogaea* has been described elsewhere. At present, GR1 and GR2 are growing at a concentration of 8.0 mM and GRS1 can tolerate upto 5.0 mM glyphosate. These cell lines grow at rates comparable to the control unselected cell line, as indicated by the FW gain of these cultures. A comparison of the growth behaviour of the herbicide tolerant cell lines in contrast to the sensitive, unselected cells challenged with increasing concentrations of glyphosate is shown in Fig.1. While growth of sensitive callus was inhibited by 50% at 0.5 mM concentration, about 10 mM glyphosate was required to achieve the same effect in the herbicide tolerant cell lines. The herbicide tolerant cell lines, therefore, showed *ca.* 20 fold increase in tolerance to glyphosate as compared to the unselected cells.

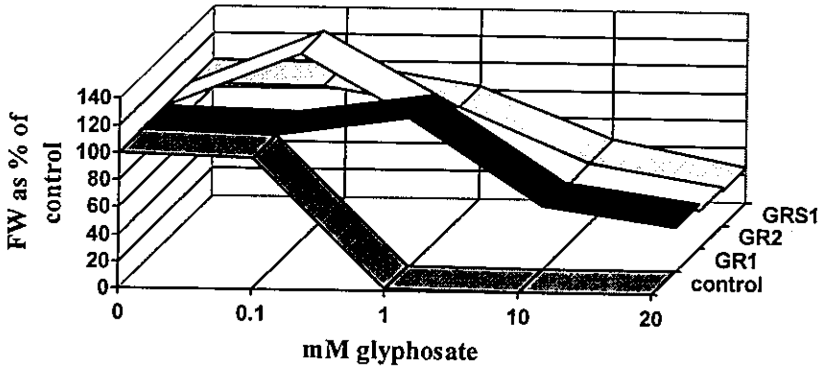


Figure 1. Effect of glyphosate on FW accumulation in glyphosate sensitive *vs.* tolerant cell lines.

*Overexpression of EPSP synthase in glyphosate tolerant cell lines*: The glyphosate selected cell lines continuously cultured in presence of the herbicide were found to have a specific activity of EPSP synthase higher than the unselected cells (Table 1). Two other key regulated enzymes of the shikimik acid pathway, namely, DAHP synthase and CM did not show any significant changes in total extractable activity. The relative abundance of immuno reactive EPSP synthase in glyphosate sensitive and tolerant cell lines was quantified by ELISA, and the data presented indicate 60-75% increase in the antigen level, comparing well with the 52-68% increase in the specific activity of the enzyme. However, EPSP synthase activities from both glyphosate sensitive and the tolerant cell lines were equally subject to inhibition by the herbicide (Fig. 2).

Table 1. Overexpression of EPSP synthase in glyphosate sensitive *vs.* tolerant cell lines.

| Enzyme | Control | GR1 | GR2 | GRS1 |
|---|---|---|---|---|
| EPSP synthase [1] | 0.190 ± 0.090 | 0.290 ± 0.040 | 0.320 ± 0.120 | 0.300 ± 0.010 |
| EPSP synthase [2] | 0.038 ± 0.011 | 0.061 ± 0.009 | 0.066 ± 0.015 | 0.065 ± 0.010 |
| DAHP synthase [1] | 1.250 ± 0.100 | 1.670 ± 0.120 | 1.200 ± 0.090 | 1.290 ± 0.090 |
| CM [1] | 0.850 ± 0.070 | 0.800 ± 0.100 | 0.750 ± 0.090 | 0.790 ± 0.070 |

1 Enzyme activity expressed as nkat/mg, nmoles/min/mg and µmoles/min/mg protein, respectively
2 Immunoreactivity (ELISA) of EPSP synthase expressed as $Abs_{450}$

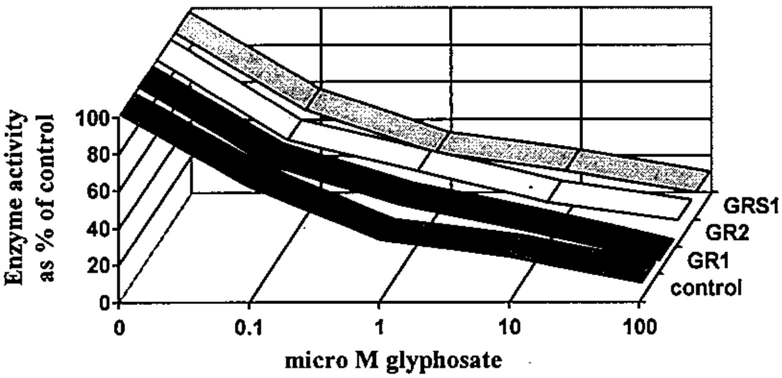


Figure 2. *In vitro* inhibition of EPSP synthase activity by glyphosate. (The control values for sensitive, GR1, GR2 and GRS1 cells were 0.22 ± 0.01, 0.32 ± 0.04, 0.36 ± 0.00 and 0.30 ± 0.02 nkat/mg protein respectively).

The results confirm that EPSP synthase is the only enzyme target for glyphosate action. Our studies, however reveal that the synthesis of the shikimic acid pathway enzymes is not subject to coordinate control. Acquisition of glyphosate tolerance in the selected cell lines appears to be *via* overproduction of the target enzyme EPSP synthase. The lack of differential effect of glyphosate on the *in vitro* enzyme activity from glyphosate sensitive and tolerant cell lines suggested that the EPSP synthase proteins from both the sources are indeed identical, and that the herbicide tolerance achieved during the selection procedure is (presumably) due to gene amplification and / or enhanced expression of the original EPSP synthase gene.

*Amplification and expression of EPSP synthase gene in glyphosate tolerant cell lines*: The genomic blots of glyphosate sensitive and tolerant cell lines, when probed with the 2.0 kb *Eco*R I *Sal* I fragment of EPSP synthase of *Bacillus subtilis* (9) showed amplification of two, 6.5 kb and 2.3 kb sized *Eco*R I fragments in the selected cell lines. No such changes were observed when the same blot was reprobed with *Entamoeba histolytica* genomic clone of actin (5) and *Arabidopsis* cDNA clone of DAHP synthase (8). The amplification of EPSP synthase gene in glyphosate tolerant cell lines is specific and genes encoding other enzymes of shikimic acid pathway do not show amplification in response to glyphosate stress, as had earlier been confirmed by biochemical characterization of the glyphosate tolerant cell lines.

To determine whether the elevated EPSP synthase activity and increased gene copy number in the glyphosate selected cell lines is also reflected at the transcription level, Northern blot analysis was conducted. A single band of approximately 1.8 kb hybridized to the *Bacillus* EPSP synthase probe. EPSP synthase mRNA in these lines was more abundant as compared to the unselected controls. The size of the *Arachis* EPSP synthase mRNA is very similar to that in *Petunia*, *Corydalis sempervirens*, tobacco and carrot (1.8-2 kb). As a control for these RNA blots, the transcript levels for actin were determined. The increase in EPSP synthase transcript level appeared to be a specific change in gene expression which could be correlated to glyphosate tolerance.

*Stability of the selected phenotype*: The cell lines were maintained on glyphosate free medium for more than two years (nearly 60 culture cycles), before transferring them back on the selection medium. All the three cell lines were found to have retained the selected phenotype, and grew at rates comparable to the lines that were grown continuously on glyphosate containing medium. Only a marginal loss in the enhanced specific activity and in the content of immunoreactive EPSP synthase was detected (Table 2).

Table 2. Overexpression of EPSP synthase in glyphosate tolerant cell lines grown on glyphosate free medium for more than two years.

| EPSP synthase | Control | GR1 | GR2 | GRS1 |
|---|---|---|---|---|
| Enzyme activity (nkat/mg protein) | 0.200 ± 0.070 | 0.260 ± 0.090 | 0.300 ± 0.040 | 0.290 ± 0.010 |
| Immunoreactive protein (ELISA, $Abs_{450}$) | 0.038 ± 0.011 | 0.054 ± 0.014 | 0.059 ± 0.009 | 0.056 ± 0.011 |

There was no appreciable change in the status of amplified EPSP synthase DNA in absence of the selection pressure for two years. The expression of the amplified EPSP synthase genes, however, did alter slightly as the Northern analysis of these cultures revealed a lowering in the EPSP synthase transcriptional activity. Decreased expression of the amplified genes without the loss of the amplified DNA has earlier been documented and associated with the methylated status of genes during tissue culture (3). The involvement of similar factors operative in the present system, so as to explain the decline in EPSP synthase mRNA expression needs to be investigated.

The work in our laboratory is currently directed towards cloning of the gene for glyphosate tolerance from these lines and studying the regulation of this very important gene. Having standardized a regeneration protocol for groundnut, attempts are also underway to regenerate the herbicide tolerant cell lines of groundnut.

## ACKNOWLEDGEMENT

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# RESISTANCE OF *PHALARIS MINOR* TO ISOPROTURON: MECHANISM AND MANAGEMENT IMPLICATIONS

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*Summary*: Continuous use of isoproturon to control grass weeds in wheat crops in a rice-wheat rotation has resulted in the evolution of resistant (R) biotypes of Littleseed canarygrass (*Phalaris minor*) in India. Experiments conducted under controlled environmental conditions has revealed that there was no alteration at the target site in the PS II reaction centre. The uptake and translocation of $^{14}C$ isoproturon in the R and S biotypes were similar, however the R biotype was found to metabolise isoproturon at a faster rate (1.4-1.8 times) compared to the S biotype. Activity studies conducted using herbicides of different modes of action exhibit some cross-resistance to diclofop-methyl. Trifluralin and pendimethalin provided good control of the R biotype but limited crop safety of the former and field inconsistency of the later are limitations in their use. Fenoxaprop and tralkoxydim, however, have been found to control the R biotype and can be successfully used in the management practices. Similarly, terbutryne, metazachlor and propachlor provided excellent control of the R and S biotypes though crop safely was limited in the case of certain compounds. Integrating herbicides of different modes of action with crop rotation and intelligent agronomic practices can help to manage resistance and further delay its occurrence.

*Keywords*: isoproturon resistance, resistance mechanism, *Phalaris minor*

## INTRODUCTION

Herbicides are analogues to weed control in rice and wheat crops in the north-western Indian states of Punjab and Haryana. The increased yield of these crops had a significant effect on the sustainability of the green revolution in India. Urea herbicides were widely adopted for the control of grass weeds notably *Phalaris minor* Retz. (Littleseed canarygrass) in these states in the early nineteen eighties. Continuous use of isoproturon in wheat under this monotonous crop rotation resulted in the evolution of resistance in *P. minor* biotypes in 1991(1, 2, 5, 6, 7). Failure to control *P. minor* using herbicides resulted in a yield loss of 30-80% and complete crop failure in many areas with severe intensity of weeds. Using herbicide mixtures of isoproturon with atrazine or fenoxaprop did not increase control of the resistant (R) biotype. Similarly addition of the surfactant (Silwet L-77, 0.05%) to isoproturon and fenoxaprop had no enhancing effect. Diclofop-methyl has already lost its efficacy due to cross-resistance in many areas. The use of pendimethalin against the R biotype provided inconsistent results due to the field conditions at spraying; its higher volume and cost were also prohibitive. Isoproturon resistance has also increased in the adjoining state of Punjab and is rapidly increasing in areas where the rice-wheat cropping system is practised. Studies of the basis of resistance showed that there was no difference in target site protein as it was equally sensitive to photosynthesis inhibition by isoproturon in R & S biotypes under *in vitro* conditions (6, 7). *In vivo,* however, photosynthesis and chlorophyll fluorescence recovery was greater in the R biotype of *P. minor* indicating faster degradation of herbicide by the R biotypes (6, 7, 10). The present investigation was carried out to understand the mechanism of resistance and to evaluate herbicides of different modes of action for effective management of the R biotypes of *P. minor*.

## MATERIALS AND METHODS

*Activity studies*: Field soil of sandy silt loam texture (low in available P, medium in K and organic matter, and a pH of 6.1) was used after mixing with coarse grit and a slow release fertiliser 'Osmocote' for planting the seeds in a glasshouse using 9 cm polystyrene pots. Plants were thinned a week after germination to maintain 6 plants per pot of each species for post-emergence herbicides. Trifluralin was mixed in soil before planting the seeds whereas the pre-emergence herbicides were sprayed a day after sowing. Herbicides were sprayed at different dose rates (Table 1 and Fig. 1 & 2) using a Mardrive laboratory sprayer fitted with a Teejet 8003 nozzle delivering 170 L/ha at 300 kPa pressure. There were four replicate pots per treatment for each species. Plants were observed periodically for visual toxicity effect and fresh and dry weights were recorded at harvest. Growth reduction ($GR_{50}$ values) were derived by probit analysis using visual mortality data. Percent reduction in dry weight over control and succulence (fresh/dry weight) were calculated for pre- and post-emergence herbicides.

*Metabolic studies*: Plants raised as earlier were used for metabolic studies at the 2-3 leaf stages. Half of the plants were sprayed with unlabelled (commercial) isoproturon at 0.25 kg a.i./ha ($GR_{50}$ dose for S biotype) using a motorised track sprayer fitted with a flat-fan even spray nozzle delivering 400 L water/ha at 270 kPa pressure, before treating with radiolabelled isoproturon. A 5 µl aliquot of $^{14}C$ isoproturon (specific activity 11.97 MBq/mg) was mixed with formulated isoproturon (Sabre 55.3% S.C.) at 0.25 kg a.i./ha to give a final concentration of 630 µg/ml isoproturon. The solution was applied to the midrib of the second oldest leaf using a Hamilton microsyringe (0.1 µCi in 0.5 µl x 10 droplets per plant). The treated plants were placed in a growth room at 24/18°C day/night temp., 80/60% RH and a photoperiod of 14 h in 24 h by fluorescent lamps (83 µE $m^{-2}$ $s^{-1}$ photon flux density). Plants harvested at 4, 24, 48 and 168 h after treating with $^{14}C$ isoproturon were extracted for metabolites using 80% methanol by homogenisation and centrifugation (14500 g for 30 min at 2°C). The pellet was washed 3 times and the combined supernatant was pooled, dried by rotary evaporator and cleaned after re-dissolving, though a C18 'Sep-Pak' (reverse phase solid phase extraction) cartridge. The aliquot was dried and re-dissolved in 80% methanol for thin layer chromatography (TLC) separation. The aliquot was applied to 20 x 20 cm silica plates (Sil 60G-25/UV 254) and metabolites were separated by chloroform:ethanol (50:50). The plates were dried and were subjected to phosphor image analyser for quantitative assay. The metabolites were identified by reference to known standards.

## RESULTS AND DISCUSSION

Isoproturon at the lowest dose (0.25 kg) caused 80% reduction in the dry weight (DW) of the S biotype and complete mortality thereafter whereas the succulence of the R biotype was only affected after 2 kg (Fig. 1a). The effect on succulence was greater on wheat compared to the R biotype at higher doses of isoproturon. Significant differences were recorded on the succulence in R & S biotypes with diclofop, the effect being more on the S compared to R biotype (Fig. 1b). Though the effect on the R biotype was greater than the crop with diclofop compared to isoproturon, it was less than the S biotypes at all dose rates. No significant differences were observed in the S & R biotypes with fenoxaprop and tralkoxydim as both reduced the fresh/dry weight greatly; wheat was not affected by either of these herbicides except at the highest dose (Fig. 1c & d).

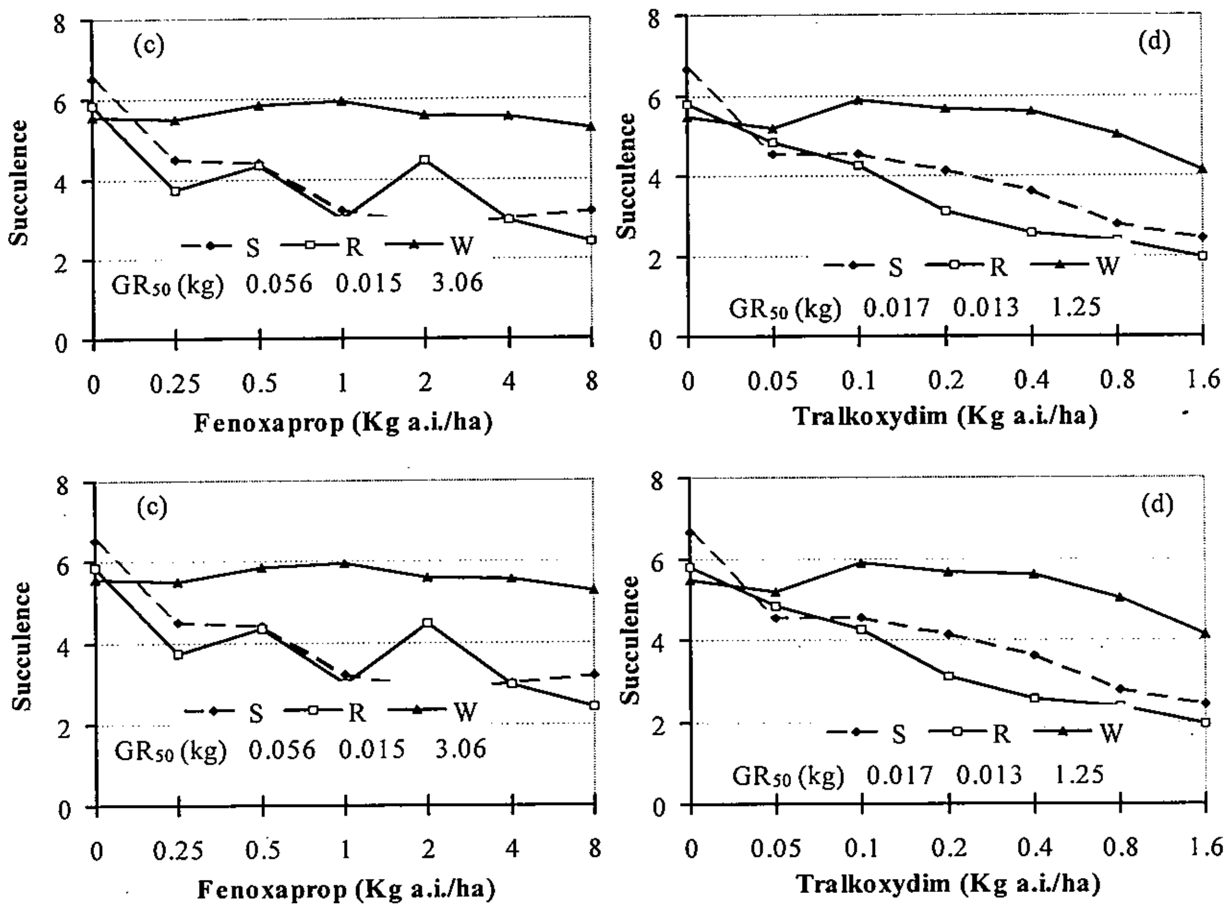


Figure 1. Effect of Isoproturon (a), diclofop (b), fenoxaprop (c) and tralkoxydim (d) on the succulence of S & R biotypes of *P. minor* and wheat

The $GR_{50}$ values of isoproturon were 12 times less for the S compared to the R biotype of *P. minor* (Fig. 1a). The R biotype required 4 times higher dose of diclofop for the same level of control compared to of the S biotype (Fig. 1b). Fenoxaprop and tralkoxydim were very effective as the $GR_{50}$ values were less than even 100 g for both R & S biotypes of *P. Minor* Fig. 1c & d) The dose required to reduce the growth of wheat by 50% was >50 times by these herbicides compared to *P. minor* biotypes (Fig. 1c & d). There were no remarkable differences in the activity of these herbicides against S or R biotypes; the differences in the $GR_{50}$ values are only because of higher mortality even at the lowest applied dose. Similarly the pre-emergence herbicides *viz.* metazachlor, atrazine and trifluralin (pre-plant incorporation) required a lower dose to effectively control both biotypes of *P. minor* irrespective of R or S (Table 1).

Terbutryne, pendimethalin and propachlor required a dose of 0.2 to 0.65 kg/ha for reduction in growth by 50% of *P. minor* biotypes and were quite safe to wheat crop. Atrazine and metazachlor exhibited slightly higher mortality to the crop but it was 3-9 times more than *P. minor* biotypes (Table 1).

Trifluralin and metazachlor caused 100% reduction in the DW at 0.25 kg/ha in both R & S biotypes of *P. minor* compared to 2. 0 kg/ha in wheat (Table 2). Atrazine and terbutryne required 0.5 and 1.0 kg/ha for complete mortality of R & S biotypes of *P. minor*, respectively. No difference was observed in the DW reduction in R & S biotypes by pendimethalin, however propachlor required slightly higher dose (Table 1). DW reduction was minimum in wheat with pendimethalin followed by terbutryne and propachlor.

Degradation of $^{14}C$ isoproturon was greater in the R biotype compared to the S biotype at all the treatment durations (Fig. 2). Plants treated with formulated isoproturon had less degradation compared to unsprayed plants of both biotypes. After 168 h only 30% of $^{14}C$ isoproturon remain undegraded in the R biotype compared to 55% in the S biotype under unsprayed conditions (Fig. 2). Under treated conditions the recovery of the parent compound (% of applied $^{14}C$ isoproturon) was 70 and 50% in the S and R biotypes, respectively. The amount of dealkylated and hydroxylated metabolites and conjugates was more in the R biotype compared to the S biotype. The total number of metabolites, however were same in both R & S biotypes.

Table 1. Effect of pre-emergence herbicides on growth reduction of S & R biotypes of *P. minor* and wheat.

| Dose (kg a.i./ha) | Trifluralin S | Trifluralin R | Trifluralin W | Pendimethalin S | Pendimethalin R | Pendimethalin W | | Terbutryne S | Terbutryne R | Terbutryne W |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0625 | 62 | 48 | 20 | 32 | 45 | 7 | | 22 | 30 | 7 |
| 0.125 | 67 | 55 | 38 | 41 | 57 | 8 | | 55 | 42 | 3 |
| 0.250 | 100 | 100 | 65 | 45 | 74 | 7 | | 70 | 78 | 6 |
| 0.500 | 100 | 100 | 72 | 71 | 68 | 6 | | 88 | 95 | 16 |
| 1.000 | 100 | 100 | 74 | 100 | 100 | 6 | | 100 | 100 | 27 |
| 2.000 | 100 | 100 | 100 | 100 | 100 | 5 | | 100 | 100 | 35 |
| GR50 | 0.11 | 0.08 | 1.49 | 0.23 | 0.40 | >4.0 | | 0.19 | 0.20 | 2.32 |
| | Metazachlor | | | Atrazine | | | | Propachlor | | |
| *Dose* (kg a.i./ha) | S | R | W | S | R | W | *Dose* (kg a.i./ha) | S | R | W |
| 0.031 | 47 | 51 | 5 | 16 | 55 | 0 | *0.125* | 38 | 0 | 0 |
| 0.0625 | 85 | 59 | 15 | 47 | 68 | 10 | *0.25* | 56 | 9 | 2 |
| 0.125 | 95 | 88 | 19 | 69 | 88 | 11 | *0.50* | 62 | 73 | 8 |
| 0.25 | 100 | 100 | 38 | 83 | 94 | 4 | *1.0* | 100 | 71 | 22 |
| 0.5 | 100 | 100 | 60 | 100 | 100 | 47 | *2.0* | 100 | 100 | 40 |
| 1.0 | 100 | 100 | 83 | 100 | 100 | 73 | *4.0* | 100 | 100 | 39 |
| $GR_{50}$ | 0.015 | 0.022 | 0.20 | 0.06 | 0.07 | 0.20 | | 0.45 | 0.65 | 4.68 |

DW (% of control)

The enhanced degradation in the R biotype seems to be mediated by P-450 monooxygenase enzymes as the degradation of $^{14}C$ isoproturon was significantly checked by the presence of P-450 inhibitors and the activity of isoproturon was greatly increased at whole plant level (10). The rate of degradation of $^{14}C$ isoproturon in the R biotype was found to be even greater than wheat (8, 9); at increased dose rates crop damage was evidenced under field conditions without providing adequate control of the R biotype. Mixture of isoproturon with fenoxaprop or with surfactant (Silwet L-77) did not provided significant improvement in the control of the R biotype (6, 7). Herbicide mixture of different modes of action has been postulated to delay and manage the resistance (11), however they were of limited success. These were costly and species specific as the efficacy of the mixture depended on the companion herbicide in controlling the R weeds (3). This kind of metabolic resistance is very serious with such a severity where complete crop loss is widespread. Lower incidence of resistance evolution were recorded in fields where farmers adopted crop rotations (2) and is a vital strategy along with rotation of herbicides with different modes of action coupled with modified agronomic practices (4).

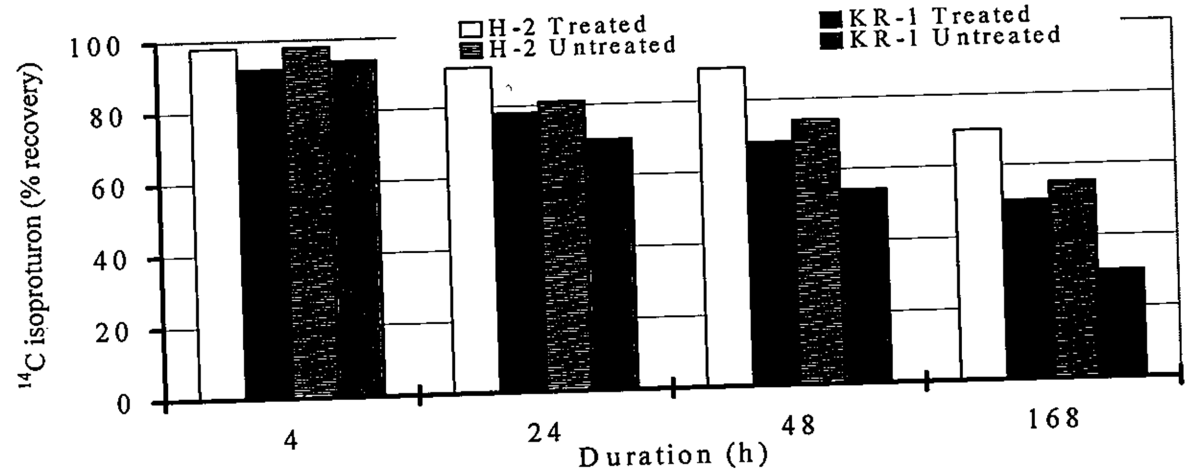


Figure 2. Degradation of $^{14}C$ isoproturon in S & R biotypes of *P. minor* with unlabelled isoproturon treated and untreated conditions

## ACKNOWLEDGEMENT

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# POTENCY OF ALTERNATE HERBICIDES AGAINST ISOPROTURON-RESISTANT LITTLESEED CANARY GRASS

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*Summary*: Pot culture experiments conducted in 1995-96 indicated that resistant biotypes (KR1 and H3) of littleseed canary grass (*Phalaris minor* Retz.) required about 8.8 to 11.2 and 6.3 to 8.0 times more of isoproturon (Tolkan, 75 WP) as compared to susceptible biotypes R1 and H2, respectively. Fenoxaprop-p-butyl (Puma Super, 10 EC) and sulfosulfuron (Mon 44900, 75 WP) were found equally effective against susceptible as well as resistant biotypes while diflufenican (Expo 4005 B, 50 WP) was not effective against any biotype. The response of tank mixture of herbicides based on isoproturon indicated that only isoproturon effect was reflected. In 1996-97, potency of four post-emergence alternate herbicides including clodinafop (Topik, 15 WP), fenoxaprop, sulfosulfuron and tralkoxydim (Grasp, 10 EC) was evaluated at 7 farmers field trials comprising four under zero-tillage sowing coupled with the use of pre-seeding herbicides, glyphosate (RoundUP, 41.8 EC) and paraquat (gramoxone 24 WSC) and three under conventional tillage system of wheat sowing. Herbicide use package under both systems of wheat sowing was found quite effective against resistant littleseed canary grass, however, its control was more under zero-tillage.

*Keywords*: resistance, alternate herbicides, zero-tillage.

## INTRODUCTION

Herbicide use against the littleseed canary grass in wheat strongly shaped the large scale yield advantage and improved the economy of farmers. Continuous use of a single herbicide, isoproturon, has now trapped farmers into the problem of resistance which got worse every year since 1992 and wiped out the gains achieved over the past 10 years starting from 1982 (3). The frequent use of a single herbicide together with monoculture of wheat has been the main cause of resistance in littleseed canary grass reported for the first time from Haryana (2). Resistant (R) biotypes of this weed now require 5 to 6.5 times more of isoproturon than susceptible (S) biotypes (4). If the situation is not tackled now, this resistance problem may put a question mark on the sustainability of rice-wheat cropping sequence (1). The quantitative changes in favour of large populations of resistant biotypes may bring about a qualitative change in the weed management package for wheat. There is a need to revitalise the sowing techniques so that mechanical methods or pre-seeding herbicides for controlling early population can be supplemented with post-emergence herbicides under zero tillage system for compensating the cost of herbicides.

## MATERIALS AND METHODS

Pot culture experiments at CCS Haryana Agricultural University, Hisar and farmers field trials in resistance prone areas were conducted during the winter season of 1995-96 and 1996-97, respectively. Pot culture experiments included seven sets of different herbicides viz.; isoproturon (0, 63, 125, 500, 1000, 2000, 4000 g/ha), fenoxaprop (0, 10, 20, 40, 80, 160 g/ha), sulfosulfuron (0, 10, 20, 40, 80, 160 g/ha) + 0.5% adjuvant (Monsanto), diflufenican (0, 12.5, 25, 50, 100, 200, 400 g/ha), isoproturon + fenoxaprop in the ratio of 15:1 (0, 63, 125, 250, 500, 1000, 2000 g/ha), and isoproturon + metribuzin (Sencor, 70 WP) in the ratio of 10:1 (0, 250, 500, 1000, 2000 g/ha), isoproturon + diflufenicon in the ratio of 10:1 (0, 63, 125, 200, 500, 1000, 2000 g/ha). Two resistant (H3 and KR1) and two susceptible (R1 and H2) biotypes of littleseed canary grass were considered for studying the potency of these herbicides. Seeds of resistant biotypes were collected from resistance affected farms located in rice-wheat zone of Haryana. Among two susceptible biotypes, R1 was a pristine population from Rohtak district of Haryana where isoproturon has never been used and H2 was collected from the experimental farm of CCS Haryana Agricultural University, Hisar where herbicides were frequently rotated and isoproturon provided excellent control of this weed. Earthen pots of 30 cm height and 15 cm top radius were filled with sandy loam soil of medium fertility which was earlier exhausted from the existing seed bank by applying water for a sufficient long period. Twenty seeds/pot were own on 15 December, 1995 and ten plants were maintained in each pot for spraying. The herbicides were applied at 3- leaf stage of littleseed canary grass with knapsack sprayer using 650 litre of water/ha. The pots were arranged in complete randomised design keeping three replicates. The dry weight of littleseed canary grass was recorded 30 days after spraying and the relative dry weight reduction (%) was subjected to probit analysis to find out GR50 (dose required for 50% growth reduction) of various herbicides against each biotype. Seven farmers field trials included four under zero till seed drill in Hisar district and three under conventional tillage system of wheat sowing in Kaithal district of Haryana. Under zero tillage wheat sowing, stale bed technique was applied by irrigating the field twice after rice harvest, then pre-seeding herbicide like glyphosate at 0.5% or paraquat at 0.3% was applied after emergence of littleseed canary grass from soil seed bank. Initial population of littleseed canary grass at different locations in three districts varied from 600 to 3000/m$^2$. After three days of spray, wheat was sown with zero till seed cum fertilizer drill without any field preparation after rice harvest. Whereas under conventional tillage system, the crop was sown with seed cum fertilizer drill in well prepared farmer's fields. The crop was sown in the last week of November, 1996 under both systems and raised with recommended package of agronomic practices. Then under both system of sowing post-emergence herbicides including clodinafop, fenoxaprop, sulfosulfuron + adjuvant and tralkoxydim at 60, 120, 25 + 0.5% and 350 g/ha, respectively were applied 30 days after sowing at each location. Data on percent control of the weed in question and grain yield of wheat was recorded at harvest.

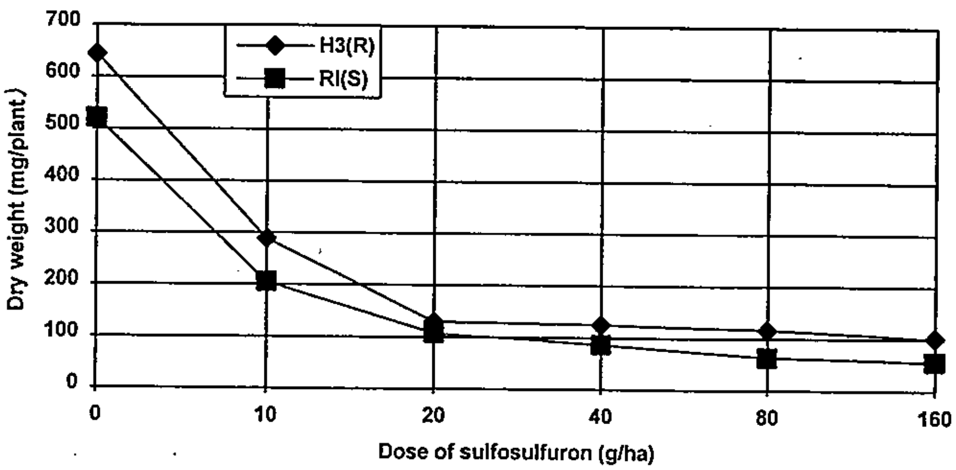
## RESULTS AND DICUSSION

Resistant biotypes of littleseed canary grass KR1 and H3 required 8.8 to 11.2 and 6.3 to 8.0 times more of isoproturon to cause 50% reduction in their dry weights (Table 1) as compared to susceptible biotypes R1 and H2, respectively. Fenoxaprop and sulfosulfuron were found equally effective against susceptible as well as resistant biotypes. GR50 in case of fenoxaprop (Table 1) ranged from 20 to 23 g/ha whereas sulfosulfuron at 20 g/ha caused 80-88% reduction (Fig 1) in the dry weight of resistant (H3) and susceptible (R1) biotypes and its phytoxicity on these biotypes increased at a similar level with the increase in its rate of application. Diflufenican alone was not effective against any biotypes (data not given). Tank mixture of herbicide based on isoproturon indicated that only isoproturon effect was reflected and the response was different in the resistant and susceptible biotypes (Table 1). Combination of fenoxaprop or metribuzin with isoproturon was less effective than the sole treatment of these herbicides.

Table 1. Probit transformed response of R & S biotypes of Phalaris minor to different herbicides in pot culture bioassay.

| Herbicide | GR5 (g/ha) levels of different herbicides | | | |
|---|---|---|---|---|
| | H3(R) | KRI(R) | RI(S) | H2(S) |
| Isoproturon | 2077 | 1978 | 246 | 315 |
| Fenoxaprop | 22.9 | 22.2 | 19.8 | 19.3 |
| Isoproturon + fenoxaprop (15:1) | 429 | 643 | 221 | 350 |
| Isoproturon + metribuzin (10:1) | 707 | 544 | 261 | 312 |
| Isoproturon + diflufenican (10:1) | 979 | 1054 | 212 | 274 |

Fig. 1. Effect of sulfosulfuron on the dry weight of R and S biotypes of littleseed canary grass.




*CD - H3(R)=19.0; RI(S)=14.0*

Data pertaining to farmers field trails (Table 2) revealed that the new herbicides viz; clodinafop, fenoxaprop, sulfosulfuron and tralkoxydim provided excellent control ranging from 82-90% of resistant biotypes resulting in grain yield of wheat from 3915 to 4506 kg/ha under zero tillage system of wheat sowing. Performance of all these four herbicides except tralkoxydim was also found quite satisfying in Kaithal district where wheat was sown with conventional tillage. However, control of littleseed canary grass was more under zero tillage system of wheat sowing.

Table 2. Effect of alternate herbicides on percent control of littleseed canary grass and grain yield of wheat under zero tillage and conventional tillage sowing.

| Herbicide | Dose (g/ha) | Zero tillage | | Conventional tillage | |
|---|---|---|---|---|---|
| | | Hisar (Av. of 4 locations) | | Kaithal (Av. of 3 locations) | |
| | | Control (%) | Grain yield (kg/ha) | Control (%) | Grain yield (kg/ha) |
| Clodinafop | 60 | 88 | 4271 | 83 | 4648 |
| Fenoxaprop | 120 | 88 | 4289 | 68 | 4363 |
| Sulfosulfuron+adjuvant | 25+.05% | 90 | 4506 | 83 | 4843 |
| Tralkoxydim | 350 | 82 | 3915 | 61 | 4076 |

The variations in field demonstrations were mainly because of differences in the stage of application at different locations. The new herbicides therefore, would need further evaluation with respect to their stage of application and volume of spray solution.

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# A SURVEY OF HERBICIDE RESISTANCE IN WEEDS FROM THE NORTHERN GRAIN REGION OF AUSTRALIA

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*Summary*: In a study of weeds resistant to chlorsulfuron and atrazine, 15 weed species were investigated. The study showed at least six weed species to have evolved resistance to one or other of these herbicides. Collections of turnip weed, Indian hedge mustard, common sow thistle, climbing buckwheat and African turnip weed were resistant to the recommended rate of chlorsulfuron (15 g a.i./ha). Collections of liverseed grass were resistant to the recommended rate of atrazine (1.8 kg a.i./ha). For four weeds (viz. turnip weed, climbing buckwheat, African turnip weed and liverseed grass) their resistance status was confirmed using a multiple dose response screen and this is the first report of resistance for these species.

*Keywords*: herbicide resistance, resistant weeds

## INTRODUCTION

An adverse consequence of repeated use of herbicides with the same mode of action there has been the emergence of resistant weed populations (3). The majority of cases have appeared in the northern hemisphere and involve resistance to triazine (4, 9, 10) and acetolactate synthase (ALS)-inhibitor herbicides (4, 8, 5). In Australia there is only one report of triazine resistance but several reports of ALS-inhibitor herbicide resistance (2). More than 100 biotypes of annual ryegrass (*Lolium rigidum* Gaudin), eight biotypes of Indian hedge mustard (*Sisymbrium orientale* L). Indian hedge mustard and one biotype of common sow thistle (*Sonchus oleraceus* L.) have been confirmed to be resistant to ALS-inhibitor herbicides (8). One biotype of *S. oleraceus* and one biotype of *S. orientale* came from the northern grain region (1). Area surveys for determining the extent of herbicide-resistance has been conducted in southern Australia on barley grass (*Hordeum glaucum* Steud.) with respect to paraquat resistance (11) but to date no similar surveys have been undertaken in the north-east grain region of Australia on weeds resistant to either chlorsulfuron or atrazine. Since little was known about the extent of resistance in the north-east grain region, the present study was undertaken.

## MATERIALS AND METHODS

*Plant material*: Seed collections were made from surviving plants at locations where chlorsulfuron (applied at rates of 10-15 g a.i./ha to wheat and barley paddocks) or atrazine (applied at rates of 1.8 kg a.i./ha to sorghum paddocks) had been used for between 0 and 11 years or 0 and 15 years, respectively. Most of these sites were not selected at random but were nominated by the Queensland Herbicide Resistance Action Committee as sites with potentially resistant weeds. Some of the sites were selected with little or no history of atrazine or chlorsulfuron use so that comparisons could be made with a susceptible weed species. Thirty sites within a 100 km radius of Goondiwindi, Queensland [plus one population of African turnip weed, *Sisymbrium thellungii* O. Schultz from Roma, Queensland] were visited where 62 seed collections were made either in October 1993 or October 1995 (referred to as winter weed seed collections). Twenty-three sites within 100 km west, south and south-east of Toowoomba, Queensland [plus two populations of parthenium weed (*Parthenium hysterophorus* L. ) from near Emerald, Queensland] were visited where 50 seed collections were made either in March 1994 or March 1995 (referred to as summer weed collection).

When seed was collected, landholders were questioned regarding the past use of chlorsulfuron and atrazine. Most landholders gave precise indications of use based on detailed records, a few gave approximate indications of use. Once returned to the laboratory all seed collections were cleaned, sorted and dried (25°C for 5 days). Once after-ripening had improved the germination percentage (indicated by regular germination tests), random seed samples from each collection were removed and tested for herbicide resistance.

*Single dose response screen*: A whole plant screening technique, using a single discriminating herbicide dose and an untreated control for comparison, was developed for detection of herbicide resistance (6). Equivalent numbers of seed of each collection were sprinkled onto the soil surface and covered with 0.5 cm of soil to create a level seed bed. Three replications of 200 summer weed seed and three replications of 100 winter weed seed were used with the exception of turnip weed which had three replications of 50 seed. The soil was a sterilized, light brown loam (< 1% organic carbon) and each replicate was contained within plastic germination trays (35 x 29 x 5 cm). The appropriate herbicide was applied immediately after sowing using a sprayer positioned approximately 43 cm above the soil surface delivering 110 L/ha (250 kPa pressure), through its flat-fan nozzles (Tee-jet 001). After herbicide treatment the seedbed was watered to field capacity and trays placed, at random, onto glasshouse benches. Seed collections made in October (winter weeds) were grown in the winter seasons of 1994, 1995 and 1996 whereas seed collections made in March (summer weeds) were grown in the summer seasons of 1994/95 and 1995/96.

Each seed collection taken from a wheat or barley paddock was tested against chlorsulfuron (Glean®; 750 g a.i./kg), and those collected from sorghum paddocks were tested against atrazine (Gesaprim® 500 g a.i./L), applied at 15 g a.i./ha and 1.8 kg a.i./ha, respectively. These were recommended field rates for these two herbicides in wheat and sorghum paddocks, respectively in the north-east grain region. Thirty days after the application of either herbicide, the number of survivors in each replicate were recorded, cut at ground level and weighed following drying at 70°C for 48 h. Assessment of herbicide resistance was undertaken following a close examination of the percentage plant survival and the percentage mean dry weight of survivors. This data was obtained following a comparison of the herbicide treatments to the untreated controls. Thus the data is shown as survival percentage (number of live seedlings in treated trays/number of live seedlings in untreated trays) and dry weight percentage (mean dry weight of treated survivors/mean weight of untreated survivors) for three replicate trays.

This single dose response screen based on the application of only one herbicide dose is unable to predict the level of herbicide resistance in each collection. However a collection was considered to be resistant if it had over 50% of its herbicide-treated individuals surviving and where the mean dry weight of the treated survivors was at least 80%. Any population that had over 50% of its herbicide treated individuals survive and where the mean dry weight of the survivors was at least 50% of the untreated control plants, was considered to be partially resistant.

*Multiple dose response screen:* For some seed collections the degree of resistance to a herbicide was further investigated using a multiple dose response screen. Four species, turnip weed, African turnip weed, climbing buckwheat and liverseed grass were studied this way. For each species at least two collections (a susceptible and a suspected resistant) were tested against a range of herbicide rates (0 through to 8 times the recommended rate). Turnip weed was tested against five rates of chlorsulfuron and metsulfuron-methyl, while African turnip weed was tested against seven rates of chlorsulfuron, metsulfuron-methyl, sulfometuron, 2,4-D and bromoxynil and climbing buckwheat against six rates of chlorsulfuron, trisulfuron, trifensulfuron-methyl/metsulfuron-methyl, picloram/2,4-D, fluroxypyr and bromoxynil. Liverseed grass (*Urochloa panicoides* Beauv.) was tested against six rates of atrazine and trifluralin. The procedure for preparation of germination trays, herbicide application and the collection of data was identical to that described above for single dose response screens. The degree of herbicide resistance was determined by an $LD_{50}$ ratio (that concentration of the herbicide required to kill 50% of the seedlings divided by the dose required to kill 50% of a susceptible collection) and a $GR_{50}$ ratio (that concentration of the herbicide required to inhibit growth by 50% divided by the dose required to inhibit growth by 50% of a susceptible collection) values using regression analysis (1).

## RESULTS AND DISCUSSION

*Resistant weeds*: Two out of five collections of turnip weed were found to be resistant to chlorsulfuron in 1995 (Table 1). They were isolated from an area that had been continuously cropped to wheat and where chlorsulfuron had been used at least 3 years. Three other collections where chlorsulfuron had been used for between 2 and 6 years were shown to be susceptible. Dose response studies on the resistant collections confirmed a greater (20-fold) $LD_{50}$ ratio (plant survival) and a greater (20-fold) $GR_{50}$ ratio (growth reduction) when compared to a susceptible collection. These collections also indicated resistance to metsulfuron-methyl.

Table 1. The number of resistant, partially resistant and susceptible collections of weed species for which at least one collection showed resistance.

| Weed Species | Total collections tested | No. collections resistant | No. collections partially resistant | No. susceptible | Herbicides tested against |
|---|---|---|---|---|---|
| turnip weed | 5 | 2 | 0 | 3 | chlorsulfuron |
| Indian hedge mustard | 13 | 3 | 3 | 7 | chlorsulfuron |
| common sowthistle | 14 | 8 | 2 | 4 | chlorsulfuron |
| climbing buckwheat | 7 | 1 | 0 | 6 | chlorsulfuron |
| African turnip weed | 4 | 2 | 0 | 2 | chlorsulfuron |
| liverseed grass | 13 | 5 | 2 | 6 | atrazine |

Three collections of Indian hedge mustard were found to be resistant to chlorsulfuron. In addition three collections were found to be partially resistant to chlorsulfuron. They had been growing on continuously cropped wheat paddocks where chlorsulfuron had been applied for at least 6 years (Table 1). Seven other collections from paddocks where chlorsulfuron had been used for between 2 to 11 years were shown to be sensitive to chlorsulfuron.

Eight collections of common sowthistle were found to be resistant to chlorsulfuron. In addition two collections were identified as partially resistant. These plants were collected in 1993 and 1995 growing on continuously cropped wheat paddocks where chlorsulfuron had been used at least once-a-year for at least 4 years (Table 1). Four other collections from paddocks where chlorsulfuron had been used for between 0 to 10 years were shown to be susceptible.

One collection of climbing buckwheat was found to be resistant to chlorsulfuron in 1994 (Table 1). It was growing on a continuously cropped wheat paddock where chlorsulfuron had been used at least once a year for 10 years. Six other collections from paddocks where chlorsulfuron had been used for between 0 to 10 years were shown to be sensitive to it. The resistant collection was highly resistant to chlorsulfuron in terms of plant survival but only moderately resistant in terms of growth reduction. Resistance was also confirmed to the other ALS-inhibitor herbicides (trisulfuron and trifensulfuron-methyl/metsulfuron-methyl. The resistant biotype was susceptible to the non ALS-inhibiting herbicides (picloram/2,4-D, fluroxypyr and bromoxynil)

Two collections of African turnip weed were found to be resistant to chlorsulfuron in 1995 growing on continuously cropped wheat paddocks where chlorsulfuron had been used for a minimum of 5 years (Table 1). Two other collections from paddocks where chlorsulfuron had been used for 6 and 10 years were shown to be sensitive to it. One of the collections was shown to have a greater than 32-fold plant survival when compared to a susceptible collection. One of the resistant biotypes was also resistant to other ALS-inhibitor herbicides (metsulfuron-methyl and sulfometuron) whereas it was susceptible to 2,4-D and bromoxynil.

Five collections of liverseed grass found to be resistant to atrazine were collected from different sorghum paddocks near Toowoomba, Queensland in 1995 (Table 1). In addition two partially resistant collections were identified. They were growing on summer cropped sites where atrazine had been used at least once-a-year for between 2 and 15 years. Six other collections from paddocks where atrazine had been used for between 0 to 15 years were shown to be sensitive to it. Dose response studies confirmed resistance to atrazine. However, it was confirmed that these resistant biotypes were susceptible to trifluralin.

*Susceptible weeds :* The winter weed collections of London rocket (*Sisymbrium irio* L.) (3 collections), wild turnip (*Brassica tournefortii* Guoan.) (2 collections), spiny emex (*Emex australis* Steinh.) (3 collections), and paradoxa grass (*Phalaris paradoxa* L.) (11 collections) were all susceptible to chlorsulfuron (data not presented). Chlorsulfuron had been applied to these weeds once a year for between 0 and 12 years. The summer weed collections of bladder ketmia (*Hibiscus trionum* L.) (12 collections), mintweed (*Salvia reflexa* L.) (9 collections), parthenium weed (*Parthenium hysterophorus* L.) (2 collections), green amaranth (*Amaranthus viridis* L.) (2 collections) and awnless barnyard grass (*Echinochloa colona* (L) Link) (14 collections) were all susceptible to atrazine (data not presented). Atrazine had been used for between 0 and 15 years.

*General discussions and conclusions*: At present there appear to be at least five dicotyledonous species (16 collections) and one grass species (five collections) with herbicide resistance. These collections represent four very important weed families (Brassicaceae, Asteraceae, Polygonaceae and Poaceae). Two of these species have been shown to be resistant to herbicides before (*S. oleraceus* and Indian hedge mustard to chlorsulfuron and other ALS-inhibitor herbicides; (1), however this is the first report of resistance in climbing buckwheat, African turnip weed, turnip weed (all chlorsulfuron) and liverseed grass (to atrazine).

This selected site study of the northern grain region has revealed that there are many sites with weeds resistant to chlorsulfuron. Most prevalent is the resistance of common sowthistle where only six of the 14 collections made did not show resistance and of these six, three were suspected to be developing resistance. The two sites where turnip weed has been confirmed resistant are within 2 km of each other. However, with African turnip weed, resistance outbreaks are located in two distinct localities at Goondiwindi, Queensland and 350 km north-west at Roma, Queensland.

The appearance of these weed populations resistant to chlorsulfuron and atrazine is clearly of great concern to various sectors of the north-east Australian grain industry. Our research has shown that for these weeds alternative herbicides can be used for control of these resistant weeds. This is confirmed by Boutsalis and Powles (1) with their work on Indian hedge mustard and common sowthistle. As well, work in the northern hemisphere has shown that triazine and sulfonylurea-resistant weeds often do not exhibit cross-resistance and are therefore controlled by alternative herbicides or combinations of herbicides with different modes of action. However a total reliance on chemicals for control of weeds could result in more cases of herbicide resistance (7). Clearly an integrated approach to weed management is needed.

## ACKNOWLEDGEMENT

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# MANAGING HERBICIDE RESISTANCE FOR WATER-SEEDED RICE IN NEW SOUTH WALES

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*Summary:* Integration of multiple modes of herbicidal action on each weed species in each season of application is a key objective for weed control programs under development for water-seeded rice in New South Wales. Alternate herbicides were sought that would offer additional modes of action to the aceto-lactate synthase (ALS) inhibition that occurs with bensulfuron on aquatic weed species. Field trial results over three seasons have shown this objective can be met by sequential application of molinate, thiobencarb, bensulfuron and MCPA sodium at rates often well below commercial label recommendations. Combining these sequences with cultural weed control techniques may offer economical, robust and durable weed management.

*Keywords*: herbicide resistance, resistant weeds

## INTRODUCTION

In New South Wales, approximately 100-150,000 ha of irrigated rice are grown annually, established principally by water-seeding (pre-germinated rice broadcast into flooded bays).

Annual aquatic weeds are favoured by constant ponding, so water-seeded rice tends to be infested with *Cyperus difformis* L. (dirty Dora, CYPDI), *Damasonium minus* Buchen. (starfruit, DAMMI), *Sagittaria montevidensis* Cham.&Schecht. (arrowhead, SAGMO) and *Alisma lanceolatum* With. (alisma, ALSLA). Cultural control methods such as clean seedbeds, clean seed, laser guided land levelling, ridge rolling, farm hygiene and water depth are all important components of weed control programs in NSW rice production, however most growers cannot reliably produce economic crops without herbicide inputs.

Bensulfuron methyl (LONDAX™) has been applied to in excess of 90% of the New South Wales rice crop (most often in combinations with molinate) for the past ten seasons, leading to the widespread development of bensulfuron-resistant populations of *C. difformis*, *D. minus* and *S. montevidensis* (1, P. Baines, pers. comm. 1996). Combination partners (with alternate modes of action) for bensulfuron in water-seeded rice production have been difficult to find as most rice herbicides are not tolerated by germinating rice seedlings, but rather are used in transplanted rice culture (5). Multiple modes of action applied in the same season as bensulfuron are viewed as an essential means to delay the development of resistance (1).

Thiobencarb is one possible partner for bensulfuron, however advanced *Echinochloa crus-galli* P.Beauv. (barnyard grass, ECHCG) and *C. difformis* can escape treatment once rice has advanced sufficiently to tolerate treatment (i.e. 1.5 leaf stage rice). Water-seeded rice will tolerate molinate at all growth stages, offering control of *E. crus-galli* and mild suppression of *C. difformis* (4). MCPA sodium presents an alternate mode action (MOA) to bensulfuron for all aquatic annual weeds of rice in New South Wales. In order to obtain adequate crop tolerance with MCPA sodium, rice must develop to the mid tillering stage prior to treatment (ie: past the bensulfuron application window), thus incurring considerable weed competition.

Propanil is the only other herbicide registered for application to water-seeded rice in New South Wales. It is not used commercially because of the difficulties associated with draining large fields (typically 20-80 ha per crop) to obtain a target for foliar application. These large fields also require long filling times (5-10 days), often resulting in advanced weed stages (relative to rice) that prevent the effective use of pre-emergence herbicides such as pretilachlor and oxadiazon.

Field studies have been conducted over three seasons to attempt the integration of molinate, thiobencarb and MCPA sodium with bensulfuron to achieve at least two modes of herbicidal action per species per year. Aspects of this research presented are:

a. Development of pre-sowing priming treatments of molinate to suppress weeds until the two leaf stage of rice (when thiobencarb can be safely applied to the crop).

b. Definition of appropriate bensulfuron rates (in tank mixtures with thiobencarb) for application to 1.5-2.5 leaf rice.

A sequence of molinate applied pre-sowing @ 1920 g ai/ha followed by thiobencarb @ 1600 g ai/ha was thought to offer the best compromise for efficacy and rice tolerance, based upon previous trials and commercial experience. Confirmation of bensulfuron rates was sought (for broadleaf aquatic weed control) when applied with this sequence Efforts to merely suppress aquatic weeds with bensulfuron prior to control with MCPA sodium (as a possible means to reduce selection pressure for bensulfuron resistance). An attempt was made to lower selection pressure for bensulfuron resistance by reducing the herbicide rate. This may have the effect of reducing the persistence of herbicidally-active soil and water residues; thus lowering both the percentage kill and the length of residual weed control. Bensulfuron rates of 3-48 g ai/ha were evaluated in combinations with molinate plus thiobencarb (+/- MCPA).

## MATERIALS AND METHODS

All field experiments were conducted at dedicated, laser-levelled sites in the Murray and Murrumbidgee valley irrigation areas during the three seasons (1994-96). Randomised complete block designs of four replications of plots typically 4.5x8 m were used, with earthen bunding and independent watering. An alternate bunding system used in some trials comprised aluminium sheeting clipped into a ring (0.5 or 1.0 $m^2$) and embedded into the mud to prevent leakage.

Normal agronomic practices were emulated, with pre-germinated seed sown by aircraft or hand. Herbicide applications were made using simulated SCWIIRT treatments (3), administering neat or concentrated working solutions directly to floodwater with a syringe or using a hand-held gas-powered small plot boom sprayer delivering 90-115 L/ha.

Trials were assessed using visual ratings of rice injury and weed control, counts of rice and weed seedling and inflorescence density and direct harvest of grain yields using Wintersteiger or Kincaid plot harvesters.

## RESULTS

Pre-sowing application of low rates of molinate improved control of *E. crus-galli* using thiobencarb plus bensulfuron mixtures (Table 1). Priming treatments were observed to impair the development of early-germinating *E. crus-galli* (and *C. difformis*) that would otherwise escape control with a thiobencarb plus bensulfuron mixture.

Table 1 Percentage control ratings of *Echinochloa crus-galli* in water-seeded rice affected by pre-sow priming treatments of molinate (subsequently treated with thiobencarb @ 3000 g ai/ha plus bensulfuron @ 30 g ai/ha at 2-3 leaf stage of rice)

| Molinate rate (g ai/ha) | Trial Number | | Average |
|---|---|---|---|
| | H24-94 | H28-94 | |
| 0 | 76.3 | 71.5 | 73.9 |
| 480 | 86.5 | 82.5 | 84.5 |
| 960 | 93.3 | 94.8 | 94.1 |
| 1440 | 99.3 | 94.5 | 96.9 |
| 1920 | 97.5 | 97.8 | 97.7 |
| c.v. (%) = | 20.7 | 16.8 | |

Low rates of bensulfuron (6-12 g ai/ha) added to a sequence of molinate @ 1920 g ai/ha followed by thiobencarb @ 1600 g ai/ha resulted in poorer weed control ratings and lower grain yields than the full commercial rate (48 g ai/ha). When bensulfuron @ 12 g ai/ha was followed by MCPA sodium however, weed control was excellent and grain yields were in excess of all other treatments (Table 2).

Many broad-leaved aquatic weeds were observed to survive the initial low rate bensulfuron treatment, albeit in a stunted and less competitive form. These were subsequently killed or severely retarded in growth by the MCPA sodium treatment.

Table 2. Visual weed control ratings and grain yields of water-seeded rice[1] after treatment with sequential programs of molinate followed by thiobencarb plus bensulfuron (+/- MCPA sodium)[2], New South Wales, 1996-97 season.

| Bensulfuron rate (gai/ha) | SAGMO | ALSPA | DAMMI | Mean | Grain yield (% of highest) |
|---|---|---|---|---|---|
| 0 | 22 | 6 | 22 | 17 | 64 |
| 3 | 52 | 55 | 76 | 61 | 68 |
| 6 | 77 | 73 | 77 | 76 | 81 |
| 12 | 89 | 86 | 92 | 89 | 83 |
| 24 | 96 | 98 | 96 | 97 | 88 |
| 48 | 98 | 99 | 99 | 99 | 89 |
| 12 followed by MCPA | 99 | 100 | 99 | 99 | 96 |

[1] Averaged over seven field experiments
[2] Molinate @ 1920 g ai/ha applied pre-sowing, thiobencarb @ 1600 g ai/ha +/- bensulfuron applied 1.5-2.5 leaf stage rice, MCPA sodium @ 500–700 g ai/ha applied 2-tillers rice.

## DISCUSSION

Initial attempts to combine thiobencarb with bensulfuron (to achieve a second MOA against *C. difformis)* were plagued by rice injury and poor control of *E .crus-galli*. Development of pre-sow priming treatments of molinate (or low rates of thiobencarb) have enabled thiobencarb to be reliably incorporated into local water-seeded rice weed control programs. Given that thiobencarb is largely inactive against Alismataceae weeds, additional MOA herbicides are needed in programs. MCPA sodium is currently the only practical alternative herbicide for this purpose.

These experiments demonstrated a rate response in aquatic weed control and grain yield over the range of 3-48 g ai/ha of bensulfuron, thus validating existing product recommendations (when used as the sole means of aquatic broadleaf weed control). Significant suppression of these weeds was noted even at the lowest bensulfuron rate evaluated. This suppression is characteristic of ALS-inhibitor herbicides, contrasting with pre-emergence herbicides such as pretilachlor that enable surviving weeds to recover and prosper; thus requiring a high initial percentage kill.

Where these low rates of bensulfuron (6-12 g ai/ha) were followed by MCPA sodium, subsequent weed control ratings and grain yields were equivalent or better than if the highest rate of bensulfuron (48 g ai/ha) was used. The low rate sequence thus achieved the optimum crop performance, whilst using two modes of herbicidal action on broad-leaved aquatic weeds and with a lower selection pressure for bensulfuron resistance.

Adoption of a low rate (e.g. 12 g ai/ha) of bensulfuron when sequenced with MCPA sodium represents a 75% reduction of a typical commercial use rate for bensulfuron. Whilst this may not greatly reduce selection pressure for bensulfuron resistant biotypes in the weed population, it also assists in reducing rice seedling injury and encourages growers to shift weed control investment into alternate mode of action herbicides (e.g. thiobencarb and MCPA sodium). Further rate definition studies with bensulfuron (sequenced with MCPA sodium) are needed to validate these results, along with computer modelling to better understand the likely effects on resistance development within aquatic weed populations.

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# AN OUTBREAK OF SULFONYLUREA HERBICIDE RESISTANCE IN SCROPHULARIACEAE PADDY WEEDS IN JAPAN

(14)

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*Summary*: Sulfonylurea (SU) herbicides have been widely used in major cereal-growing areas to control or suppress broadleafs and some sedges since their introduction in the early 1980s. Especially, bensulfron-methyl (BSM) and pyrazosulfuronethyl (PSE) were used at most eight years as one shot treatment herbicides, e.g. Zark (BSM / mefenacet) in Japan. In the spring of 1996, annual paddy Scrophulariaceae weeds *Lindernia micrantha* D. Don. (Japanese name: Azetogarashi), in Yoshijima, Kawanishi Town, and *Lindernia dubia* Pennell (subsp. typica, Japanese name: Taketo-azena) in Nakayoshide, Yuza Town, Yamagata Prefecture were observed to be resistant to SU herbicides. Also, we found resistant *L. dubia* subsp. *major* Pennell (Japanese name: Amerika-azena) in somepaddy areas in Akita and Miyagi Prefecture. *Lindernia pyxidaria* L. (Japanese name: Azena) and *Limnophila sessiliflora* Blume (Japanese name: Kikumo) were also not controlled not only by SU herbicides but also mefenacet in the Tohoku district. It may be concluded that the resistant biotypes of these Scrophulariaceae weeds are about 100 times more resistant to all SUherbicides than the susceptible ones. The biotypes were observed to infest paddy fields and unplanted or partly unplanted rice fields. In these fields, we observed that Zark 25 granule applied continuously for 3 to 7 years failed to control these weeds. Combination of Solnet granule (400 g a.i./ha for pretilachlor) and Kumilead-SM granule (240 g a.i./ha MCPB, 450 g a.i./ha for simetryn and 3.0 kg a.i./ha for thiobencarb) gave good control of all resistant weeds.

(15)

*Keywords*: herbicide resistance, sulfonylurea resistance, ALS, *Lindernia*

## INTRODUCTION

Sulfonylurea (SU) herbicides have been widely used in major cereal-growing areas to control or suppress broadleafs and some sedges since their introduction in the early 1980s. With the repeated use of the same SU-based herbicides, several weed species have developed resistance to SU herbicides. The first two confirmed cases of SU resistance following selection by chlorsulfuron were reported in *Kochia scoparia* L. (11) and *Lactuca serriola* L. (9) Since then, resistance to acetolactase synthase (ALS) inhibitors has been reported in 12 additional weed species. At least one resistant biotype of a species or more of these species has been confirmed in the USA and Canada, as well as in Australia, Denmark, UK and Israel (12). Most SU resistant weeds were collected from fields where winter wheat was grown ana were chlorsulfuron or chlorsulfuron plus metsulfuron-methyl had been applied for 3 to 5 years (16). From 1992, SU-resistant paddy weeds have also been collected from paddy fields, where bensulfuron-methyl (BSM) was applied in California, USA and Australia on *Cyperus difformis* L. and *Sagittaria montevidensis* L. subsp. *calycina* (12). Until then, our interest in herbicide resistance in Japan had been paraquat resistance in some Composite species (6). In this paper, we report several paddy weeds species resistant to SU herbicides in northern Japan with repeated use of one-shot treatment herbicides continuously for 3 to 7 years.

## MATERIALS AND METHODS

*Field survey*: Field surveys were conducted in the rice growing season from early June to late July in 1996 in the areas shown in Fig. 2 where problems of non-effective one-shot treatment herbicides occurred. At the time of survey, the paddy fields were before or just after mid-season drainage, and from 2 to 7 weeks after herbicide treatment.

*Identification of species*: Densities of each remaining weeds were checked, the weeds collected, and cultivated in submerged condition in pots in Omagari, with normal BSM concentrations. At flowering time, we identified (10) and pressed the species and also collected the seeds.

*Field experiment*: Field experiments were carried out in the rice season of 1996 in Ogawara, Matsukura, Omagari-City, Akita Prefecture and Tajiri Town, Miyagi Prefecture to verify the statement of three rice growers concerning the SU resistance of *L. dubia* subsp. *major* and *L. pyxidaria*. Each experiment consisted of fourteen rice patches and twice or 3 times typical herbicide rates were applied in late May to June. Three weeks after the treatment, the surviving weeds were recorded.

Table 1. Weed species resistant to sulfonylurea herbicides in the paddy fields in northern Japan

| Scientific name | Japanese name | Finding year | Finding place | References |
|---|---|---|---|---|
| *Monochoria korsakowii* | Mizuaoi | 1995 | Hokkaido | 7, 8, 17 |
| *Cyperus flaccidus* | Hinagayaturi | 1995 | Toyama | 4, 15 |
| *Lindernia micrantha* | Azetogarashi | 1996 | Yamagata | 2, 4, 5 |
| *Lindernia dubia* | Taketo-azena | 1996 | Yamagata & Miyagi | 1, 4, 10, 18 |
| *L. dubia subsp. major* | Amerika-azena | 1996 | Akita & Miyagi | 3, 13, 14, 18 |
| *Lindernia pyxidaria* | Azena | 1997 | Yamagata & Akita | 3, 18 |
| *Limnophila sessiliflora* | Kikumo | 1997 | Akita | 3 |

## RESULTS AND DISCUSSION

Fig.1 shows the usage of sulfonylurea herbicides in paddy fields in northern Japan. Use of one-shot treatment herbicides was decreasing with rice season. At most rice fields in northern Japan farmers used one-shot treatment herbicides mixed with some SU herbicides.

Weeds resistant to SU herbicides as of March 1997 and their locations in the paddy fields in northern Japan are listed on Table 1 and Fig. 2. All species are annual weeds. A few years ago, one-shot-treatment herbicides (eg. Zark = BSM / mefenacet) failed to control *M. korsakowii* in Naganuma Town, Hokkaido Prefecture (7) and *C. flaccidus* in Toyama City (15) in transplanted rice fields.

In July 1994, Mr. Syozabruo Sasaki (whose farm is about 10 km north of Yonezawa City, Yamagata Prefecture) observed that Zark granule (G) (BSM:75g, mefenacet: 3kg a.i./ha) applied ten days after transplanting of rice failed to control *L. micrantha* in rice monoculture fields (5). In August 1995, Mr. Masashi Komatsu (whose farm is about 15 km north of Sakata City, Yamagata) observed that Push G (BSM: 75g, dimepiperate: 3 kg a.i./ha) applied seven days after sowing of rice seed followed by Zark G at 4 weeks failed to control *L. dubia* in water-seeded ricefields (1). These fields have been in continuous rice cultivation with same herbicides continuously for 3 to 7 years.

In 1996 and 1997, several other farmers observed Zark G failed to control *L. dubia* subsp. *major*, in Aomori (13), Akita and Miyagi, *L. pyxidaria* in Yamagata and Akita, and *Limnophila sessiliflora* in Akita (3).

We now recognized resistant and susceptible biotypes of each species except *C. flaccidus*. Seventy to 300 times more sulfonylurea is now necessary to control the populations in these fields (2, 17, 18).

It has been hypothesized that when a herbicide is used repeatedly, there was very strong selection pressure against non-resistant individuals. And then the susceptible biotype is relatively easily wiped out by all SU herbicides. In the case of Japanese paddy fields, usually different herbicides of different mode of action were mixed and used in a rice season, before one-shot-treatment herbicides were recommended. Also, the weed species spectrum of the compounds (eg. mefenacet, esprocarb, etobenzanide etc.) coupled with SU were relatively narrow (4). Good combination for the resistant weeds was Solnet granule (400 g a.i./ha pretilachlor) and Kumilead-SM granule (240 g a.i./ha MCPB, 450 g a.i./ha simetryn and 3.0 kg a.i./ha thiobencarb). In a field with resistant weeds, other kinds of herbicides must be applied or mixed with SU (4).

The inheritance and the population genetics of SU herbicide resistant species need to be examined in greater detail.

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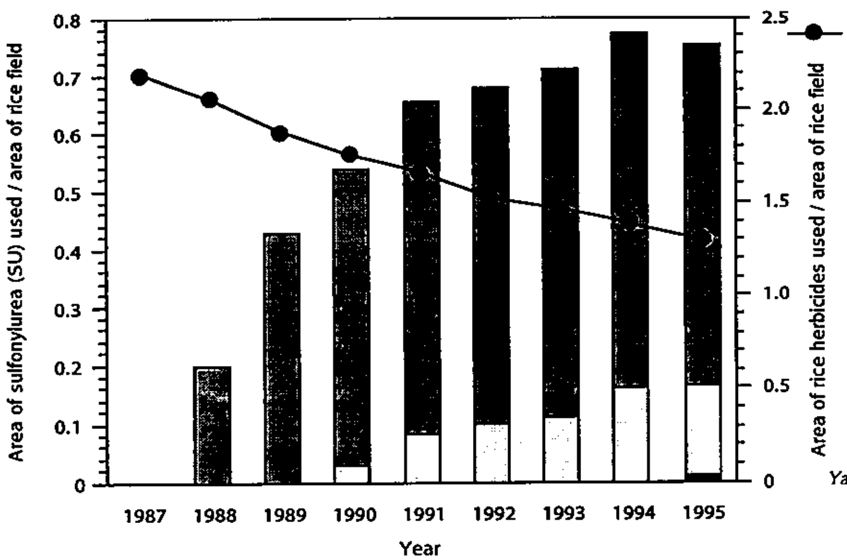


Fig. 1. The amount of SU-based herbicides used in the Tohoku district of Japan

■ : Bensulfuron-methyl □ : Pyrazosulfuron-ethyl
■ : Imazosulfuron —●— : A total of rice herbicides

*(Source form JAPR)*

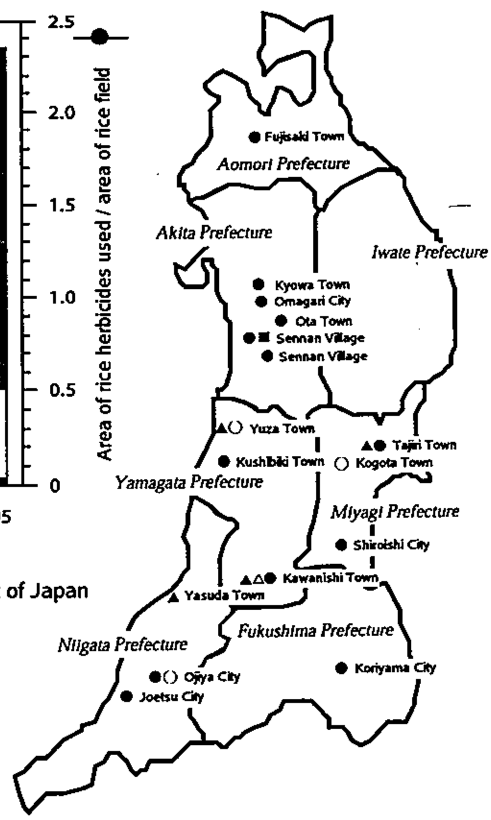


Fig. 2. The area where *Lindernia* weeds were ineffectively controlled or suppressed by one-shot application herbicides including sulfonylureas in 1996.

● *Lindernia dubia* var. *major*
○ *L. dubia* var. *dubia*
▲ *L. pyxidaria*
△ *L. micrantha*
■ *Limnophila sessiliflora*

# PROPANIL RESISTANT BARNYARD GRASS (*ECHNINOCHLOA CRUS-GALLI* L. BEAUV.) IN SRI LANKA

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*Summary*: Development of resistance in *Echinochloa crus-galli* collected from two rice-growing sites in Sri Lanka to propanil [N-(3,4-dichlorophenyl)propanamide] was investigated. Plants from N1 site (not previously exposed to propanil) were successfully controlled by the herbicide. About 29% of plants from N2 site (continuously exposed to propanil) resumed growth overcoming the initial toxicity of propanil at the recommended rate (2.8 kg/ha). At higher rates of propanil, % recovery in N2 decreased but seed germination of the weed was enhanced. Repeated use of propanil would increase *E. crus-galli* populations in rice fields due to development of resistance.

*Keywords*: propanil, *Echinochloa crus-galli*, herbicide resistance

## INTRODUCTION

Propanil [N-(3,4-dichlorophenyl)propanamide] has become the most popular and widely used rice-herbicide to control grassy weeds, especially *Echinochloa crus-galli* (L.) Beauv, because of its high selectivity on rice. *Echinochloa crus-galli* is known as the principal weed of rice (2). At present in Sri Lanka, propanil accounts for about 80% of the total volume of sales of rice herbicides. However, in the recent past there have been complaints by farmers in rice-growing areas that propanil in some locations have failed to provide effective control of this weed. These areas are subjected to continuous use of propanil for more than a decade. Thus it was suspected that the poor control of *E. crus-galli* by the herbicide propanil is due to development of resistance. Therefore, the present study was conducted to elucidate any propanil resistance development in *E. crus-galli* collected from different rice-growing areas in Sri Lanka.

## MATERIALS AND METHODS

Seeds of matured *Echinochloa crus-galli* plants were collected in August-September 1996 from two rice-growing sites, one with no previous exposure to propanil (N1; Mid country wet zone) and the other with continuous use of propanil for more than a decade (N1; North dry zone). The *E. crus-galli* seeds were treated with 0.01 N $HNO^3$ solution for 24 h to break dormancy, and germinated on moist filter paper. The germinated seeds were transformed into plastic trays of 45x34x6 cm. The trays were filled with top soil and 150 germinated seeds were sown at a rate of 150 seeds/tray. The experiments were conducted in a complete randomized design with four replicates. Treatment means were compared by the d.m.r.t. at p=0.05.

The morphological and phenological development of the two weed populations were studied. In a separate experiment, propanil (formulated as 36% E.C.) was applied at four different rates namely 2.2, 2.8, 3.6, and 4.3 kg/ha at 3 leaf stage of the weed. All the experiments were carried out in the plant house of the Faculty of Agriculture, University of Peradeniya, Sri Lanka. The average temperature was 31±0.4°C.

Weed count, unaffected plants, % kill and % recovery was recorded at 7 and 15 days after treatment. The plants that showed initial symptoms of propanil toxicity but developed new shoots and resumed growth were considered as recovered plants. Weed populations with more than 10% recovery was considered to have developed resistance. Germination of *E. crus-galli* (healthy seedlings only) after application of propanil was recorded.

## RESULTS AND DISCUSSION

*Phenological development*: The *E. crus-galli* plants from N1 site flowered at 12 weeks after planting (WAP) while those from N2 took 15 weeks. The differences in time of flowering may be due to the genetic make up of the plant populations. Tillering was not observed in plants in the present experiment. The leaf appearance and number of leaves showed no significant difference between the two plant populations. The maximum number of leaves was 8/plant in *E. crus-galli* collected from both sites, which was achieved in 4 weeks after establishment.

*Morphological development*: The leaf area and plant dry matter in *E. crus-galli* from N1 site increased at a higher rate from 10-14 weeks after planting than those from N2 site (Table 1). However, at younger stages the plants from both populations showed a similar leaf area indicating that there is no difference in receptivity area of the foliar herbicides such as propanil. However, leaf area of plants from N2 site was significantly lower than that of N1 during the latter stages of vegetative growth. Plant dry weight followed a similar trend to that of leaf area indicating that higher leaf area is instrumental in increasing photosynthetic activity and thus increasing the plant dry matter (3).

*Development of resistance to propanil*: Application of propanil at 2.2 kg/ha showed the lowest % kill in both sites indicating that this rate is not adequate for a satisfactory control of *E. crus-galli* (Table 2). Increasing the rate of the herbicide enhanced the % kill.

Although the recommended rate of propanil (2.8 kg/ha) showed a 96% kill of *E. crus-galli* from N1 site, only 71% of plants from N2 site was successfully controlled. In N2 population, 29% of plants were able to overcome the initial phytotoxicity of propanil and resume growth (recovery). Increase in the rate of application reduced the % recovery but the highest rate of propanil used in this study (4.3 kg/ha) still showed a % recovery higher than 10% (Table 2). The results indicate that there is a possibility of resistance development in *E. crus-galli* collected from N2 which was a rice-growing site subjected to continuous application of propanil for more than a decade. Continuous application of propanil has been reported to lead to development of resistance in *E. crus-galli* in Greece (1). The variations in morphological and phenological characters may also lead to the development of resistance.

Table 1. Leaf area ($cm^2$/plant) and plant dry matter (g/plant) of *E. crus-galli* collected from two sites.

| Time (weeks) after establishment | Leaf area N1 | Leaf area N2 | Plant dry matter[1] N1 | Plant dry matter[1] N2 |
|---|---|---|---|---|
| 2 | 0.7±0.2 | 0.6±0.1 | 8.2±1.8 | 8.1±0.8 |
| 4 | 1.6±0.1 | 1.7±0.8 | 10.2±1.4 | 13.1±2.6 |
| 6 | 4.7±1.1 | 10.7±2.5 | 14.7±2.6 | 23.4±5.2 |
| 8 | 14.0±2.6 | 14.3±2.1 | 59.8±4.1 | 37.1±4.7 |
| 10 | 17.1±4.2 | 26.6±5.2 | 117.0±8.2 | 42.7±7.4 |
| 12 | 47.2±3.7 | 36.6±3.4 | 142.3±6.9 | 126.4±9.8 |
| 14 | 53.2±4.8 | 44.1±4.1 | 198.2±9.2 | 138.2±8.4 |

Values are means ± s.e.

Table 2. Percentage kill and recovery of *E. crus-galli* collected from two sites (15 days after treatment).

| Rate of Propanil (kg/ha) | N1 % kill | N1 % recovery | N2 % kill | N2 % recovery |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 2.2 | 76.2±3.1 | 23.8±2.1 | 69.1±2.5 | 30.9±1.6 |
| 2.8 | 90.1±4.5 | 9.9±3.4 | 71.2±3.0 | 28.8±2.3 |
| 3.6 | 95.8±2.6 | 4.2±1.0 | 75.8±2.8 | 24.2±4.1 |
| 4.3 | 97.2±2.1 | 2.8±1.2 | 89.1±1.7 | 10.9±2.0 |

Values are means ± s.e.

*Late germination*: Late germination of plants from both sites were enhanced by the application of propanil (Table 3). Interestingly, the propanil resistant N2 plants showed a higher % germination after application of propanil when compared to those of N1. The germination percentage in the pot experiments was comparable with that of the Petri dish assay (data not shown). The results suggest that late germination of *E. crus-galli* after application of propanil could result in higher weed competition in rice fields. Although there is no clear evidence as to how propanil enhances germination of *E. crus-galli* the possibility of chemical scarification cannot be ruled out.

Table 3. Seed germination % of *E. crus-galli* after time of application of propanil in tray experiment (observations made at 15 days after treatment).

| Rate of Propanil (kg/ha) | N1 % | N2 % |
|---|---|---|
| 0 | 0 | 0 |
| 2.2 | 16.3±2.0 | 15.9±3.5 |
| 2.8 | 8.2±1.5 | 18.2±2.0 |
| 3.6 | 4.2±2.5 | 38.4±4.6 |
| 4.3 | 9.9±1.0 | 21.1±3.2 |

* mean±s.e.

The results indicate that *E. crus-galli* plants grown in rice fields in Sri Lanka that were continuously exposed to propanil for more than a decade had developed resistance to the herbicide. Thus, propanil may not effectively control *E. crus-galli* in these rice fields. The induced germination in *E. crus-galli* after propanil treatment needs serious attention as this may aggravate the problem of this weed in lowland rice cultivation.

## ACKNOWLEDGEMENTS

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# A BIOTYPE OF GOOSEGRASS CROSS-RESISTANT TO THE 'FOPS' AND 'DIMS' AND ITS MANAGEMENT

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*Summary*: A biotype of goosegrass from Alor Setar was confirmed to be resistant to fluazifop. The weed is also cross-resistant to other aryloxyphenoxyproprionate (fop) herbicides, propaquizafop and clodinafop, and a cyclohexanedione (dim) herbicide, sethoxydim. Resistance was 64 times the recommended rates for the fops and more than 64 times (maximum rate tested) for the dim. Compared to the native biotype from Rembau, the resistant biotype was shorter and more prostrate in growth, tillered profusely and was less leafy. The offspring of this biotype of goosegrass were susceptible to glyphosate, glufosinate and CGA 77'102, a pre-emergence herbicide. These herbicides are alternatives in addition to cultural practices in managing resistant goosegrass in subsequent cropping seasons.

*Keywords*: cross-resistance, *Eleusine indica*, resistance management

## INTRODUCTION

In Malaysia, goosegrass (*Eleusine indica* (L.) Gaerth.) is a ubiquitous annual grass in cultivated cropland. In a recent survey (5), goosegrass is considered a serious weed in vegetables, fruits, corn and rubber. It competes with crops for nutrients and water, hinders field operations and hosts a range of pests and diseases. However, it is fairly well-controlled by mechanical cultivation and herbicides applied pre-planting, pre-emergence or post-emergence to the crop.

The first report of Malaysia goosegrass biotypes collected from resistant to fluazifop (butyl ester) was in 1989 (3). The biotypes were treated with fluazifop at the recommended rates 2 to 3 times a year in the preceding 4 to 5 years. Resistance was established at 200-fold under glasshouse conditions. The studies also confirmed cross-resistance to several aryloxyphenoxypropionate (fop) and cyclohexanedione (dim) herbicides (3, 4). In 1994, we received news that propaquizafop failed to control a biotype of goosegrass in a vegetable farm in Alor Setar, Kedah, Malaysia. On inquiry, this biotype of goosegrass was previously subjected to repeated applications of fluazifop for several years. The information seemed to indicate a high possibility of cross-resistance within the fop and dim chemistries.

This paper reports our investigation of cross-resistance of the biotype of goosegrass from Alor Setar to the fop and dim herbicides. We also report the study of possible multiple-resistance to other herbicides of different chemistries frequently used in vegetable farms and the implications for resistance management.

## MATERIALS AND METHODS

A suspected resistant biotype of goosegrass from Alor Setar and a native biotype found on the Novartis R&D Station Rembau were sown in seed trays on 3 October, 1995 and 3 July, 1996. At the 2 to 3 leaf stage, the seedlings were transplanted in the field in rows 50 cm apart. Herbicides were applied on 3 November, 1995 to investigate cross-resistance and on 6 August, 1996 to study multiple-resistance at the early tillering stage when the seedlings were 10-15 cm tall. Weed control was assessed by visual estimation of biomass reduction as compared to untreated check plots at 7, 15 and 30 days after application. We also recorded the growth habits of the two goosegrass biotypes. All surviving plants were killed with glyphosate to prevent the spread of resistant plants on the station.

*Cross-resistance*: The herbicides used were fluazifop at 100-25'600 g/ha, propaquizafop at 25-6'400 g/ha, clodinafop at 10-2'560 g/ha and sethoxydim at 100-25'600 g/ha. All these herbicides, except for clodinafop, are commercial products used in vegetable farms for selective control of grasses.

*Multiple-resistance*: The herbicides investigated were glufosinate at 250-2'000 g/ha, glyphosate at 360-2'880 g/ha, propaquizafop at 50-400 g/ha, CGA 77'102 at 20-1'760 g/ha. As CGA 77'102 (containing the active isomer of metolachlor) is a pre-emergence herbicide, seeds of goosegrass were broadcast in bands onto the soil before application.

## RESULTS AND DISCUSSION

*Cross-resistance:* The biotype of goosegrass from Alor Setar was resistant to all the fops and the dim. However, the biotype from Rembau was susceptible to all the herbicides applied at the recommended commercial rates (Table 1).

Table 1. Biomass reduction of two biotypes of goosegrass at 30 days after application of the herbicides.

| Herbicide | Rate (g/ha) | Dose[1] | Control of goosegrass: Biotype from Rembau (%) | Control of goosegrass: Biotype from Alor Setar (%) |
|---|---|---|---|---|
| Untreated check[2] | 0 | | 30 | 25 |
| Fluazifop | 100 | 0.25 x | 96 | 3 |
| | 400 | 1 x | 100 | 5 |
| | 1'600 | 4 x | 100 | 68 |
| | 6'400 | 16 x | 100 | 93 |
| | 25'600 | 64 x | 100 | 99 |
| Propaquizafop | 25 | 0.25 x | 95 | 0 |
| | 100 | 1 x | 100 | 23 |
| | 400 | 4 x | 100 | 75 |
| | 1'600 | 16 x | 100 | 94 |
| | 6'400 | 64 x | 100 | 99 |
| Clodinafop | 10 | 0.25 x | 92 | 0 |
| | 40 | 1 x | 100 | 0 |
| | 160 | 4 x | 100 | 17 |
| | 640 | 16 x | 100 | 94 |
| | 2'560 | 64 x | 100 | 99 |
| Sethoxydim | 100 | 0.25 x | 57 | 0 |
| | 400 | 1 x | 99 | 10 |
| | 1'600 | 4 x | 100 | 7 |
| | 6'400 | 16 x | 100 | 65 |
| | 25'600 | 64 x | 100 | 91 |

[1] Dose at 1 x is the recommended rate.
[2] Data in untreated check are weed covers.

For all herbicides except sethoxydim, the recommended rates at 1x completely eradicated the susceptible goosegrass. Even underdosing by 4 times, the herbicides controlled over 90% of the weed. This was expected because the susceptible goosegrass biotype was at the active growing stage of tillering at application. In contrast, the herbicides controlled less than 25% of the biotype from Alor Setar at the recommended rates and less than 75% at 4x the recommended rates. Even at the maximum dose rate of 64x, none of the herbicides could completely eradicate the weed. The results confirm that the biotype of goosegrass from Alor Setar was resistant to fluazifop and cross-resistant to propaquizafop, clodinafop and sethoxydim.

Previously, Marshall *et al.* (4) also reported similar findings with a susceptible biotype of goosegrass collected from Malaysia completely killed at 250 g/ha or higher of fluazifop while the resistant biotype survived the herbicide at 4'000 g/ha, the maximum rate investigated. In subsequent physiological and biochemical studies, resistance was not due to differential uptake, translocation or metabolic degradation at the whole plant level (3). Instead, resistance was the result of insensitivity of the target enzyme, acetyl co-enzyme A carboxylase, to fluazifop in the resistant biotype and a mutation to the herbicide target site was suggested (2).

The resistant biotype from Alor Setar was shorter, more prostrate, less leafy and tillered more than the susceptible biotype from Rembau. These observations also confirmed those of Marshall *et al.* (4), but they did not report on the exact source in Malaysia of their resistant biotype.

*Multiple-resistance:* In this investigation, both biotypes of goosegrass were equally susceptible to the herbicides applied with the exception of propaquizafop, where the response of the resistant biotype was again reproduced. The commercial non-selective herbicide, glyphosate, and the pre-emergence herbicide, CGA 77'102, achieved complete rate (Table 2). With CGA 77'102 (the active isomer of metolachlor) being effective, we also would expect metolachlor to be effective on the resistant biotype.

Table 2. Biomass reduction of two biotypes of goosegrass at 30 days after application of pre-emergence and post-emergence herbicides.

| Herbicide | Rate (g ai/ha) | Dose[1] | Control of goosegrass | |
|---|---|---|---|---|
| | | | Biotype from Rembau (%) | Biotype from Alor Setar (%) |
| Untreated check[2] | 0 | | 24 | 16 |
| Propaquizafop | 50 | 0.5 | 95 | 0 |
| | 100 | 1 | 93 | 0 |
| | 200 | 2 | 100 | 62 |
| | 400 | 4 | 100 | 78 |
| Glufosinate | 250 | 0.5 | 68 | 60 |
| | 500 | 1 | 98 | 98 |
| | 1000 | 2 | 100 | 100 |
| | 2000 | 4 | 100 | 100 |
| Glyphosate | 360 | 0.5 | 99 | 99 |
| | 720 | 1 | 100 | 100 |
| | 1440 | 2 | 100 | 100 |
| | 2880 | 4 | 100 | 100 |
| Alpha-metolachlor | 220 | 0.5 | 98 | 99 |
| | 440 | 1 | 100 | 100 |
| | 880 | 2 | 100 | 100 |
| | 1760 | 4 | 100 | 100 |

[1] Dose at 1 x is the recommended rate.
[2] Data in untreated check are weed covers.

These results showed that there was no multiple-resistance in this particular biotype of goosegrass that was cross-resistant to the fops and a dim. CGA 77'102 or its mixed isomers of metolachlor, glyphosate and glufosinate are available tools that can manage this resistant biotype subjected to heavy selection pressure from fluazifop.

*Resistance management:* The fops and dims are highly selective herbicides on grasses. The repeated use of such herbicides have produced resistance in a number of weed species including *Lolium multiflorum*, *Lolium rigidum*, *Avena fatua*, *Avena sterilis*, *Setaria viridis*, *Setaria faberii*, *Digitaria sanguinalis* and *Sorghum halepense* (1, 7, 8). In this study and previous reports (3, 4), goosegrass has also developed cross-resistance to these highly selective herbicides. The similarities of the resistant biotype from Alor Setar to those biotypes previously studied (3, 4) appears to suggest that a mutation in the target site is present in some populations of goosegrass in Malaysia. Repeated use of a fop or dim will select for the resistant biotype in these populations.

In a resistance management strategy, irrespective of whether or not resistant populations have built up, cultural practices should be incorporated together with rotation of herbicides of different mode of action (6). If a resistant biotype of goosegrass is present on a farm, it is necessary to contain and, later, eradicate the weed, if practical. In the farmer's cycle of operations, light cultivations such as rotovations preceding a correct and evenly applied dose of a pre-emergence herbicide such as metolachlor or CGA 77'102 will eliminate the current flush of germinating seedlings. Escapes and later flushes could be spot-treated with one of the non-selective herbicides such as glufosinate before the seed heads begin to form. At the end of the relatively short vegetable crop cycle and/or fallow period, non-selective herbicides such as glyphosate or glufosinate could be used to ensure seed heads do not form. However, it must be realised that once established, a seed bank of resistant goosegrass could not be eradicated quickly within a season or two. As with diluting effects, one can only reduce it to insignificant level through sustained rounds of integrated weed management.

## CONCLUSION

A biotype of goosegrass from Alor Setar was resistant to fluazifop and cross-resistant to propaquizafop, clodinafop and sethoxydim, but was susceptible to glufosinate, glyphosate and CGA 77'102. This absence of multiple-resistance to the chemistries tested represents opportunities in managing goosegrass efficiently together with cultural practices in an integrated programme.

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# WEED COMMUNITY DYNAMICS IN DIRECT SEEDED RICE - WHAT WE STILL NEED TO KNOW

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*Summary*: This paper briefly discusses the ecological principles underlying the dynamics of rice weed communities. Consideration is given to the role of factors determining spatial and temporal heterogeneity in the rice habitat and the coexistence of rice weeds. It is concluded that insufficient is known about the biology and ecology of most rice weed species to identify the major mechanisms underlying stability in rice weed communities. Comparative studies of the persistence of seeds in the soil, of the effects of tillage and water management on recruitment in weed communities and the role of competitive release after weed control interventions are urgently needed to begin developing an understanding which will lead to sustainable weed management practices.

*Keywords*: direct-seeded rice, weed dynamics

## INTRODUCTION

Weed communities of direct seeded rice are highly dynamic entities that respond strongly both to environment and weed management. Alterations in the relative abundance of weed species have been well documented both in response to change in rice agriculture (transplanting to direct-seeding) (7) and to individual components of weed management, for instance herbicide usage (6) and manual weeding (8). In rainfed lowland rice, Khotsimuang *et al.* (9) report that years with lower than average rainfall leading to periods of little or no standing water are characteristically associated with increased weed presence and changes in the composition of the weed flora. Moody (13) also comments that in rainfed rice, terrestrial, semi-aquatic and aquatic plants may occupy the same field at different times of the year, despite the diversity of interventions undertaken in rice monoculture. In this paper we briefly consider some of the factors discussed by Moody (13) and others governing weed community composition with emphasis on a broad ecological perspective .

## ECOLOGICAL CONSIDERATIONS

Monoculture rice cropping arrests the growth of populations of weed species by four main events; by periodic and almost total plant biomass destruction at crop harvest, by tillage practices in seedbed preparation, by manipulation of competitive interactions (planting time, seeding and fertiliser rate) during the growth of the crop-weed community and by selective removal of weeds at various stages throughout the life of the crop. In entirety these events act to interspecifically select weed species from the available contenders in the natural plant community such that typically a restricted assemblage of weed species co-habits with the crop (14). Whilst surveys indicate that particular weed communities are characteristic of rice ecosystems, soil types and localities (19), there are guilds of weeds which are commonly associated with large-scale crop yield loss and in which some species (e.g. *Echinochloa* spp.) are ubiquitous. Conventional wisdom (4) argues that crop monocultures are unstable, being particularly vulnerable to invasions and farmers often refer colloquially to weed communities as 'unpredictable' but at the same time emphasize that certain species are often 'dominant'. The long term persistence of guilds of weeds points to mechanisms that both confer resilient to management and to stability in weed communities. Clearly, understanding these mechanisms is essential if effective weed management practices are to be advanced.

Ecologists have long described communities as 'stable' or 'unstable'. In a rigorous ecological sense, a stable community is one that when perturbed from an equilibrium returns to its original state, this return being independent of time scale (24). However stability in plant communities can be described in a number of ways in relation to the form of responses to perturbation and the range of environmental conditions in which it is observed (23). Restricting the view of community structure to solely one of species relative abundance, a stable weed community is defined here as one that tends to exhibit the same species composition over cropping seasons. Hypotheses for stability in crop weed communities may be based on equilibrium and non-equilibrium based mechanisms. The latter invoke fluctuation in environment or external biotic pressures as the principal cause of stability in community composition. Interspecific competition, niche differentiation and competitive release underlie equilibrium based explanations in which demographic processes regulate population sizes. These hypotheses however are not mutually exclusive since regulation of plant population size arises through the interaction of density dependent and density independent factors (3). It could be argued that the cyclical habitat disturbance associated with cropping cycles is the more important determinant of community dynamics and stability: without it perennial species become established as many studies of old field succession show. However it may be more useful to consider this disturbance to be a relatively constant feature of the habitat in which competitive interactions take place. After all, as many authors have pointed out competitive ability (and hence the outcome) of competition is not a species attribute but depends upon both environmental conditions and the other plant species involved. Seasonal disturbance can be seen as preventing large scale successional change whilst competition drives smaller scale community dynamics within the *milieu* of an arrested successional stage. Weed management practices are therefore seen as modifiers of the intensity and form of these competitive interactions. Within this conceptual framework, the dynamics of weed species in a rice weed community over cropping seasons are likely to be dominated by the outcome of demographic events at two key phases in the life cycle of weeds - recruitment of individuals from the propagule bank and the ultimate seed return resulting from plants surviving competitive interactions during crop growth. Perturbations to the weed community introduced by weed management practices characteristically focus on these phases.

Spatial and temporal variability in rice fields and niche differentiation amongst weed species are the most obvious causes of the persistence of weed species. Spatial heterogeneity may arise not only from lack of uniform application of control measures but also at crop establishment. Variations in temporal recruitment of new plants into a community can in themselves promote stable coexistence if periods of strong and poor recruitment of different species are asynchronous. Two criterion (21) must be met to promote coexistence - environmental fluctuations must be such that each species has periods of strong recruitment when it is at low density; and generations must be overlapping. Life history characteristics such as persistent seed banks (generation overlap) and plasticity in growth form and polycarpy (high reproductive output) are species attributes that may contribute to such stability. Niche differentiation in weed species is most likely to occur through temporal separation of resource acquisition (15). Variation in life span, episodic emergence and plastic phenological responses are traits that potentially enable coexistence in a competitive community.

## CULTURAL AND WEED MANAGEMENT PRACTICES AS PERTURBATIONS OF WEED COMMUNITIES

*Harvesting, fallow and tillage practices*: Land management practices determining the habitat between rice cropping cycles can result in a life history phase when weed seed and seedling mortality may be exceptionally high. Such mortality is deliberately encouraged by farmers in stale seedbed preparation but may also occur during rice straw management and during tillage in land preparation. The extent to which these processes influence community structure in the coming season will be governed by seed dormancy and the likelihood of mortality of seeds and seedlings on and within the soil profile prior to crop sowing. The long term persistence of seed banks will tend to buffer changes to weed communities but relatively little is known about the cumulative losses arising from harvesting, fallow management and tillage for individual species. In particular the influence of rice straw burning on fallow seed populations appears unquantified.

Watanabe *et al.* (22) reported distinct differences in the survival of viable buried seeds when comparing *Echinochloa* species and *Ischaemum rugosum* in relation to water management. Their data suggest that in all species studied the proportion of viable seeds in buried seed banks declined fastest (at least 70% loss per cropping season) in continually flooded soil but in rice field conditions these rates of loss were characteristically reduced, in the case of *Echinochloa oryzicola* down to 44% per season. It is as yet unknown whether mortality risks vary noticeably amongst species within the soil profile. With the assumption that the number of viable seeds throughout soil horizons are in equilibrium with respect to seasonal seed distribution and incorporation mechanisms, some insight may be gained from estimates of viable seed population sizes within the soil profile of farmer's fields. Sahid *et al.* (20) indicate that species are vertically distributed in a non-uniform way which in some cases varied according to method of crop establishment. At 10-15 cm depth seed populations of *Utricularia aurea* and *Sphenoclea zeylanica* were the most abundant in dry and wet-seeded irrigated rice fields, whereas *Scirpus juncoides* and *Fimbristylis miliacea* were most abundant in volunteer seedling fields, relying on rainfall for moisture. Critical studies of germination and emergence of rice weeds emphasise that in some species at least (e.g. *S. juncoides* and *F. littoralis)* (18), subtle germination polymorphisms exist in relation to oxygen and temperature requirements, which in turn will relate to dormancy mechanisms governing the persistence of buried seeds at depth and germination when returned to the surface layers.

Observations such as these suggest that tillage practices in burying seeds may have a noticeable effect on weed community structure. However, Baki (cited in 1) concluded from a three year study that no consistent changes in species diversity could be attributed solely due to tillage regime and argued that significant changes in weed communities were more likely to be due to crop season and weed management practices and strongly influenced by initial community composition. It is, nevertheless, likely that weed species shifts will occur with the prolonged practice of conservation tillage.

*Water management*: It is well known that water management in irrigated direct-seeded rice is a strong determinant of the weed flora where both time and depth of flooding dramatically determines establishment success in for example *S. zeylanica*, *Echinochloa crus-galli* and *Leptochloa chinensis* (17). Poor land levelling leading to different water depths and duration may in consequence lead to patchiness in weed seedling emergence but also gaps in wet-seeded rice where land drainage is non-uniform and poor crop establishment results. Fujii and Cho (5) report that even where land levelling results in a standard deviation of the field level of 3-4 cm, the field area vacant of crop is about 5%. Spatial habitat heterogeneity at the recruitment stage may thus be seen as a mechanism promoting non-equilibrium stability in rice weed communities.

Mashhor (11) indicated that land associated with irrigation canals provided opportunities for weed ingress into paddy. Whilst aquatic perennials were noted as probably the main migrants, canal banks were also the habitat of many weeds species common to rice fields. The extent to which irrigation water is a significant source of immigrant seeds is at best anecdotal and almost certainly spatially variable depending on the distribution of weed species along canal banks.

*Crop establishment and husbandry*: Moody (12) reported that a major source of weeds in direct-seeded rice is through the use of contaminated crop seed. As seed cleaning methods vary both quantitatively and selectively in removing weed seeds, they constitute a means by which spatial and temporal variation in community composition may be perpetuated.

Studies of critical periods of weed competition point to the importance of competitive interactions early in the life of the crop. Not only do competitive hierarchies often establish within the first 10 days after seeding (DAS) and strongly determine final rice yield but also weed species abundance and weed seed return at harvest. To what extent then, do weed species naturally coexist in rice fields and do weed management practices promote coexistence of weed species?

Autecological observations suggest temporal niche separation might arise through variable emergence and flowering time. In direct-seeded rice many weed species do show extended patterns of seedling emergence. Watanabe *et al.* (22) reported that whilst the majority of seedlings of *L. chinensis, F. miliacea, Cyperus* species, *S. juncoides, Monochoria vaginalis* and *Ludwigia hyssopifolia* germinated in the first 30 DAS, cohorts of seedlings were still recruited after this period. Further more in some tropical grasses at least (e.g. *Rottboellia cochinchinensis)* (16) there is a substantive ecotypic variation in flowering time. However in the absence of critical comparative measurements of emergence, flowering and seed setting time amongst weed species within rice crops it is impossible to hypothesize whether any mixtures of species might naturally coexist. Given such observations, it will still require critical experimentation to demonstrate temporal niche separation. It may well be that crop competition may promote coexistence by reducing the intensity of interspecific competition amongst weeds and thus limiting the tendency for competitive exclusion of any one species.

Interventionist weed control practices such as chemical and manual weeding may constitute a major factor promoting non-equilibrium stability of weed communities. Baki and Azmi (2) catalogue the subtlety of chemistry, timing and dose in herbicidal selection of taxonomic groups (dicotyledons, grasses and sedges) within the weed flora of direct-seeded rice. Such weed control methods have pronounced effects on the composition of the weed flora both in the short and long term as a number of studies (8) have shown. The inference is that removal of some species results in competitive release of others. Seasonal variability in selective weed control will thus alternately favour differing components of the weed flora in a non-equilibrium manner.

## CONCLUDING REMARKS

There is a natural tendency in weed management to see the plant community at the field level as a binary mixture of weeds and crop. The frequently declared goal of weed management is to introduce instability into weed communities in the sense that regardless of species, there is consistent decline away from the community that would otherwise tend to arise. Understanding the underlying factors governing the dynamics of communities and their potential stability is important if individual control tactics are to be critically evaluated as part of a strategy of weed management. Three concluding remarks can be made in this regard.

Comparative studies of the biology and ecology of individual weed species in field conditions throughout the *entire* life cycle are invaluable in exposing mechanisms leading to species persistence. But of greatest immediacy in direct-seeded rice is measurement of the longevity of buried seed populations within the soil, and the influence of tillage and water management on seedling emergence patterns. Knowledge of weed species responsiveness is crucial to the design of rotational tillage and water management regimes that may be deployed to reduce the size of the community of buried seed banks as a whole but especially weedy rices. Measurement of the persistence of buried seed populations enables a timescale to be placed on the duration and types of rotation sequence.

The literature indicates that advocates of individual weed control tactics in rice (e.g. herbicides) frequently report control efficacy in relation to residual weed biomass after control. Whilst some attention is paid to the community structure of surviving weeds, whether or not these individuals survive to reproduce, and their relative reproductive output is rarely reported. Certainly many of the major weeds of direct-seeded rice are highly fecund when at low density within rice crops (10). It is important to know the relative contribution of such survivors to weed communities of forthcoming crops.

Rice weed community structure may be largely determined by spatial variability in rice fields. If this is the case then it is important to identify the various causes and their relative contribution to habitat heterogeneity. Whilst it may be argued that uniformity in herbicide application, land levelling and broadcasting of seed are all important, each has its attendant social and economic costs. Identifying those which can be changed most easily, for the most effect, and for the least cost is a necessary first step.

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# BIOMETRIC ANALYSIS OF *ECHINOCHLOA* WEED COMPLEX

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*Summary*: About 150 accessions of *Echinochloa* weeds were collected at various locations in two prefectures in Japan, grown in a transplanting experiment under uniform field conditions, and their 13 morphological characters were applied using principal component analysis to quantitatively study variation in *Echinochloa* weeds. Analyses of data from natural habitats and the transplanting experiment showed almost identical results, and the first two principal components collectively accounted for about 70%; the first and second components reflected the spikelet size and plant shape, respectively. When plotted by species and variety on a scatter diagram between the two components, *E. oryzicola* Vasing. (= *E. phyllopogon* Koss.) and *E. crus-galli* Beauv. var. *praticola* Ohwi apparently differed in spikelet size and there was a distinct segregation between them. *Echinochloa crus-galli* Beauv. var. *formosensis* Ohwi (= *E. glabrescens* Munro ex Hook.) distributed between the former two weeds. *Echinocchloa crus-galli* Beauv. var. *crus-galli* largely varied on the scatter diagram and were continuous with *E. crus-galli* var. *praticola*, but the former weed collected at flooded rice fields had positive values at the first component and differed a little from those in other habitats.

*Keywords*: *Echinochloa*, biometric taxonomy, habitat segregation of weeds

## INTRODUCTION

*Echinochloa* weeds in Japan comprises of two species : *E. oryzicola* (Vasing.) Vasing. (= *E. phyllopogon* Koss., 2n=4x=36, hereafter oryzicola) and *E. crus-galli* (Linn.) Beauv. (2n=6x=54). The latter species differentiates into three varieties (3); var. *formosensis* Ohwi (= *E. glabrescens* Munro ex Hook.), *praticola* Ohwi and *crus-galli* (hereafter formosensis, praticola and crus-galli, respectively). All of these weeds, excluding are praticola, widely distribute in Asian-Pacific countries (1, 2, 3, 5).

Both oryzicola and formosensis are obligate rice paddy weeds, and praticola is confined to habitats with dry soil conditions. Crus-galli is widely distributed from rice paddy to uplands. For identification of *Echinochloa* species and varieties, shape of their spikelet appendage is an important qualitative character. The empty glume of oryzicola is large and acute, but those of the three varieties of *E. crus-galli*; *i.e.,* formosensis, praticola and crus-galli, are small and subacute (3, 4). Among the three varieties, formosensis differs from praticola and crus-galli. The former has a convex and shiny first floret lemma, whereas the latter have flat and rough lemma. It is not always easy to identify the latter two varieties since they are common in these qualitative characters. Yabuno (4) indicated that praticola has smaller spikelet size, leaf width and plant height than crus-galli, and its spikelet is awnless. However, the present author thinks, from observations of many plant and specimens, that praticola is an extreme group of crus-galli and the morphological characters of praticola are continuous with crus-galli.

In the experiments reported herein we tried to apply a mathematical biometry technique to *Echinochloa* complex collected from various habitats of our nearby two prefectures and relate the results with the conventional taxonomy by Yabuno (3).

## MATERIALS AND METHODS

About two hundred accessions of *Echinochloa* weeds were collected at various locations in Kyoto and Shiga Prefectures during their heading period from early July to end September in 1987. Collection sites in a location included rice paddy, paddy levee, roadside, open-land and upland crop fields. The criteria we used for collection were an accession per site, but more than an accession were collected when morphologically different types were present at a site. Each accession were identified according to Yabuno (3), and specimens kept at our Weed Science Laboratory. Seedlings prepared from seeds of each accession were transplanted to a field under uniform conditions in 1991. Thirteen characters of their morphology, listed in Table 1, were recorded for plants from both the original natural habitats and transplanting experiment. Plant type (the degree of opening at the first node), depth of purple anthocyanin pigmentation of flag leaf margin and panicle as well as the length of spikelet awn were considered as quantitative characters and visually rated on a scale from none (0), moderate (1) to severe (2). Data obtained were biometrically analyzed by principle component analysis using the personal computer application of the SPSS for Windows ( SPSS Inc., Chicago, IL).

## RESULTS AND DISCUSSION

Table 1. Morphological characters of *Echinochloa* plants collected at different habitats.

| Characters[1] | Paddy field | Paddy levee | Openland | Roadside | Upland crops |
|---|---|---|---|---|---|
| N[2] | 88 | 12 | 35 | 17 | 19 |
| SPLA (mm) | 5.7 ± 0.9 | 4.8 ± 1.2 | 4.4 ± 0.7 | 4.4 ± 0.6 | 4.4 ± 0.8 |
| SPLB (mm) | 2.5 ± 0.6 | 1.9 ± 0.6 | 1.8 ± 0.4 | 1.8 ± 0.4 | 1.8 ± 0.3 |
| SPW (mm) | 2.7 ± 0.4 | 2.3 ± 0.6 | 2.1 ± 0.3 | 2.1± 0.2 | 2.1 ± 0.3 |
| SPWEI (mg) | 3.5 ± 1.2 | 2.2 ± 1.7 | 1.7 ± 0.7 | 1.5 ± 0.7 | 1.8 ± 0.8 |
| PLT | 0.4 ± 0.7 | 0.8 ±0.8 | 1.2 ± 0.8 | 1.6 ± 0.7 | 1.6 ± 0.7 |
| PLH (cm) | 103 ± 19 | 62 ±16 | 69 ± 35 | 57 ± 25 | 82 ± 34 |
| FLL (cm) | 19 ± 5 | 12 ± 3 | 13 ± 6 | 13 ± 3 | 16 ± 5 |
| FLW (mm) | 12 ± 3 | 8 ± 3 | 10 ± 5 | 9 ± 4 | 11 ± 5 |
| FLC | 0.6 ± 0.6 | 0.9 ± 0.8 | 1.1 ± 0.8 | 1.2 ± 0.6 | 1.2 ± 0.7 |
| CLD (mm) | 45 ± 11 | 27 ± 10 | 39 ± 23 | 27 ± 13 | 37 ± 17 |
| PAL (cm) | 16 ± 4 | 11 ± 3 | 12 ± 5 | 11 ± 4 | 14 ± 4 |
| PAC | 0.5 ± 0.7 | 1.2 ± 0.8 | 1.1 ± 0.6 | 1.4 ± 0.6 | 0.9 ± 0.9 |
| PAW | 0.3 ± 0.6 | 0.1 ± 0.3 | 0.5 ± 0.8 | 0.4 ± 0.8 | 0.4 ± 0.7 |

[1]SPLA, spikelet length; SPLB, empty glume length; SPW, spikelet width; SPWEI, spikelet weight; PLT, plant type; PLH, plant height; FLL, flag leaf length; FLW, flag leaf width; FLC, flag leaf margin color; CLD, clum diameter; PAL, panicle length; PAC, panicle color; PAW, panicle awn.

[2]The number of plants surveyed.

*Variation of Echinochloa complex by habitats*: *Echinochloa* weeds collected in rice fields had apparently larger mean values of spikelet length and weight, 5.7 mm and 3.5 mg, respectively, than those at other habitats (Table 1). They also had taller plants and longer flag leaf, and this indicated that they were larger in plant and spikelet size. Plant type of the paddy weeds was rather erect as indicated by the smaller mean value of plant type rating, i.e., 0.4 ±0.7. *Echinochloa* weeds in upland fields of soybeans and broad-leaved vegetables had smaller plant height and spikelet size than paddy weeds, but had larger rating value for anthocyanin pigmentation at leaf margin and spikelets. They were also characterized by plant type rating at 1.6 ±0.7, which indicated that they were decumbent.

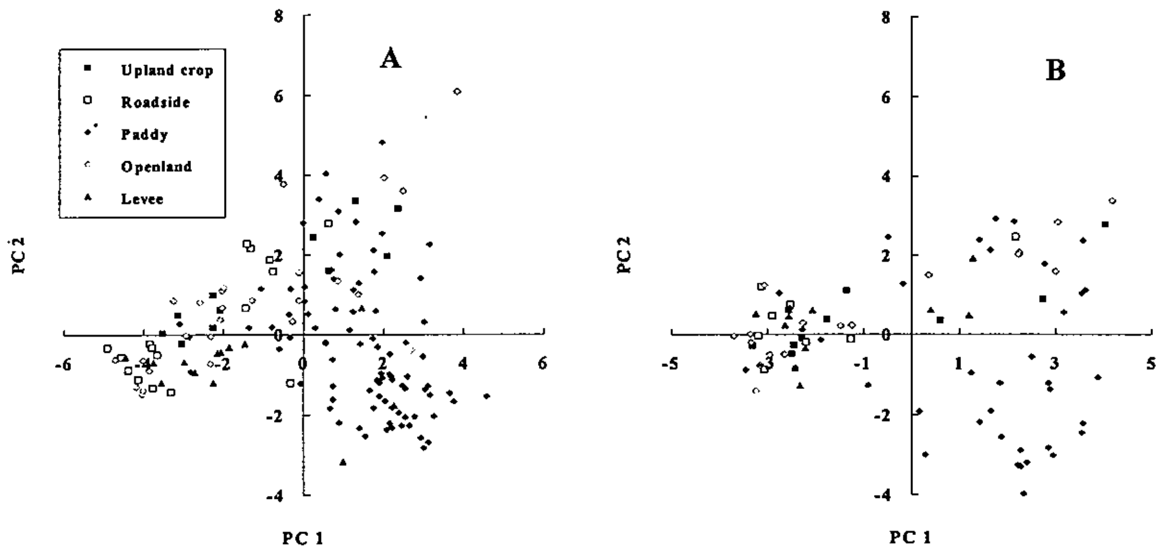


Figure 1. Scatter diagram between the first two principal components of *Echinochloa* weeds at natural habitats (A) and at transplanting experiment (B). Weeds were grouped by the habitats shown in the legend.

Table 2. Eigen values and proportions of the first three principal components.

| Characters[1] | Natural habitats | | | Transplanting experiment | | |
|---|---|---|---|---|---|---|
| | PC 1 | PC 2 | PC 3 | PC 1 | PC 2 | PC 3 |
| SPLA | 0.369 | -0.184 | 0.245 | 0.346 | -0.185 | -0.274 |
| SPLB | 0.341 | -0.226 | 0.272 | 0.280 | -0.289 | -0.304 |
| SPWID | 0.354 | -0.234 | 0.226 | 0.309 | -0.166 | -0.392 |
| SPWEI | 0.351 | -0.225 | 0.230 | 0.340 | 0.060 | -0.352 |
| PLT | -0.214 | 0.307 | 0.124 | -0.043 | 0.456 | -0.196 |
| PLH | 0.313 | 0.242 | -0.056 | 0.332 | 0.111 | 0.217 |
| FLL | 0.287 | 0.220 | -0.283 | 0.323 | 0.148 | 0.324 |
| FLW | 0.222 | 0.429 | -0.008 | 0.309 | 0.291 | 0.090 |
| FLC | -0.182 | 0.126 | 0.372 | -0.178 | 0.391 | -0.174 |
| CLD | 0.276 | 0.329 | -0.039 | 0.320 | 0.226 | 0.148 |
| PAL | 0.290 | 0.290 | -0.184 | 0.327 | 0.081 | 0.426 |
| PAC | -0.168 | 0.218 | 0.612 | -0.131 | 0.440 | 0.224 |
| PAW | 0.054 | 0.409 | 0.340 | 0.144 | 0.345 | -0.269 |
| Eigen value | 5.85 | 2.89 | 1.23 | 6.17 | 3.25 | 1.10 |
| Proportion (%) | 44.99 | 22.26 | 9.45 | 47.48 | 24.97 | 8.46 |
| Cumulative (%) | 44.99 | 67.25 | 76.70 | 47.48 | 72.45 | 80.91 |

[1]See Table 1 for the abbreviations.

Principal component analysis was applied for *Echinochloa* weed complex with thirteen morphological characters (Table 2). Proportions of the first and second components were 45 and 22% for plants in natural habitats and 47 and 25% for those of the transplanting experiment, respectively. The first component was largely contributed by the size characters such as spikelet length and weight, plant height, flag leaf length and width. The second component was contributed by the shape characters of plant type, and by the degree of anthocyanin pigmentation on flag leaf margin and panicles. Scatter diagram between the first and second components exhibited that the plants present in rice paddy fields had characters different from the others (Fig. 1). Most of them were distributed in the first and fourth quadrants of the diagram, indicating that they were larger in size characters and smaller in the shape characters. On the contrary, plants in habitats other than rice paddy were distributed from the first to third quadrants, but not in the fourth quadrant. It was thus indicated that they largely varied, but differed in morphology from those in rice paddy fields.

Table 3 shows mean values of the 13 morphological characters recorded for plants in natural habitats and the transplanting experiment. Oryzicola apparently had the largest spikelet length and width, and the spikelets weighed 4.5 ± 0.9 and 3.0 ± 0.9 mg in natural habitats and in transplanting experiment, respectively. It was also characterized by small rating values for plant type and anthocyanin pigmentation on leaf margin and panicles. Formosensis had the second largest spikelet size and small rating values for plant type and anthocyanin pigmentation. However, praticola had the smallest spikelet size and plant height.

*Variation of Echinocloa weeds by species and varieties*: Plants in natural habitats were identified according to Yabuno (3). All of oryzicola and formosensis were those collected in rice paddy fields. On the contrary, 41 among 45 praticola were collected at paddy levee, roadside and openland with dry soil conditions. Crus-galli was found on various sites of the collection.

Plants in the scattered diagram were grouped by species and varieties (Fig. 2). Both oryzicola and praticola were well clustered in the diagram; oryzicola in the fourth quadrant and praticola in the third cluster. It thus indicated that oryzicola was large in size characters represented by the first component and small in shape characters represented by the second component. Particola was small both in the size and shape characters.

Present results of principal component analysis of *Echinochloa* weed complex were apparently reflected by several unique characters of oryzicola and formosensis which were confined to rice paddies. They have larger spikelets, erect plant type and no or little anthocyanin pigmentation on panicles and flag lead margins (Table 3). The plant type appears to be adaptive for them to grow with rice having the same plant type, and the larger spikelets support them for germination under flooded conditions. We previously reported that the spikelets anaerobically germinated through alcohol fermentation, an inefficient respiratory pathway (Yamasue *et al.*, 1989). Principal component analysis made again with crus-galli and praticola data at transplanting experiment showed Cumulative proportion of the first two components was 72%, and the first and second components were also contributed by size and shape characters, respectively. There was neither segregation between crus-galli and praticola in the diagram which was derived with the 13 quantitative characters (Fig. 3), nor any qualitative characters for classifying them. But crus-galli originating from rice paddy fields were distributed only in the first and fourth quadrants, and it has larger spikelet and plant size than those from the other habitats. Our preliminary studies also suggested that in several strains representing crus-galli the habitat had anaerobic seed germinability and lower tolerance to soil drought conditions.

Table 3. Mean morphological characters of *Echinochloa* weeds surveyed at their natural habitats in 1987 and at a transplanting experiment in 1991.

| | | Mean ± st. diviation | | | |
|---|---|---|---|---|---|
| Character[1] | Conditions[2] | Oryzicola | Formosensis | Preticola | Crus-galli |
| n[3] | N | 57 | 18 | 46 | 45 |
| | T | 25 | 16 | 33 | 46 |
| SPLA (mm) | N | 6.5 ± 0.5 | 5.3 ± 0.4 | 4.0 ± 0.4 | 4.9 ± 0.6 |
| | T | 5.2 ± 0.7 | 4.6 ± 0.2 | 3.7 ± 0.3 | 4.5 ± 0.4 |
| SPLB (mm) | N | 3.0 ± 0.5 | 2.0 ± 0.3 | 1.6 ± 0.2 | 2.0 ± 0.3 |
| | T | 2.2 ± 0.5 | 1.8± 0.2 | 1.4 ± 0.2 | 1.7 ± 0.3 |
| SPW (mm) | N | 3.0 ± 0.2 | 2.5 ± 0.2 | 0.9 ± 0.1 | 2.3 ± 0.2 |
| | T | 2.6 ± 0.3 | 2.4 ± 0.2 | 2.1± 0.2 | 2.4 ± 0.2 |
| SPWEI (mg) | N | 4.5 ± 0.9 | 3.0 ± 0.6 | 1.2 ± 0.2 | 2.3 ± 0.6 |
| | T | 3.0 ± 0.5 | 2.7 ± 0.4 | 1.2 ± 0.2 | 1.9 ± 0.4 |
| PLT | N | 0.1 ± 0.3 | 0.4 ± 0.7 | 1.2 ± 0.8 | 1.3 ± 0.8 |
| | T | 0.1 ± 0.3 | 0.3 ± 0.4 | 1.1 ± 0.5 | 1.4 ± 0.7 |
| PLH (cm) | N | 98.9 ± 17.2 | 98.9 ± 17.8 | 53.2 ± 23.9 | 99.8 ± 29.1 |
| | T | 121.9 ± 19.9 | 136.7 ± 21.3 | 86.4 ± 20.0 | 134.8 ± 21.5 |
| FLL (cm) | N | 18.1 ± 4.3 | 21.0 ± 4.9 | 12.1 ± 4.5 | 17.5 ± 5.8 |
| | T | 21.1 ± 5.4 | 24.8 ± 4.8 | 15.2 ± 5.5 | 23.2 ± 5.7 |
| FLW (mm) | N | 10.3 ± 1.6 | 12.4 ± 2.6 | 7.2 ± 3.2 | 12.5 ± 3.5 |
| | T | 12.6 ± 2.7 | 15.6 ± 2.3 | 10.5 ± 3.1 | 16.1 ± 3.2 |
| FLC | N | 0.4 ± 0.7 | 0.9 ± 0.8 | 1.2 ± 0.6 | 0.9 ± 0.8 |
| | T | 0.2 ± 0.5 | 0.5 ± 0.7 | 1.2 ± 0.5 | 1.1 ± 0.6 |
| CLD (mm) | N | 43 ± 6 | 51 ± 10 | 24 ± 14 | 48 ± 16 |
| | T | 47 ± 11 | 60 ± 11 | 34 ± 12 | 59 ± 13 |
| PAL (cm) | N | 14.6 ± 2.4 | 18.6 ± 3.8 | 9.6 ± 3.4 | 15.3 ± 3.7 |
| | T | 17.6 ± 3.9 | 23.1 ± 5.7 | 12.1 ± 3.8 | 18.6 ± 3.5 |
| PAC | N | 0.4 ± 0.7 | 0.6 ± 0.7 | 1.1 ± 0.7 | 1.0 ± 0.7 |
| | T | 0.2 ± 0.6 | 0.5 ± 0.7 | 1.2 ± 0.6 | 1.2 ± 0.6 |
| PAW | N | 0.0 ± 0.2 | 0.1 ± 0.2 | 0.1 ± 0.3 | 0.8 ± 0.9 |
| | T | 0.1± 0.4 | 0.1 ± 0.3 | 0.0 ± 0.2 | 0.8 ± 0.9 |

1 See Table 1 for the abbreviations.

2 N, plants at natural habitats; T, plants at transplanting experiment.

3 The number of individual plants surveyed.

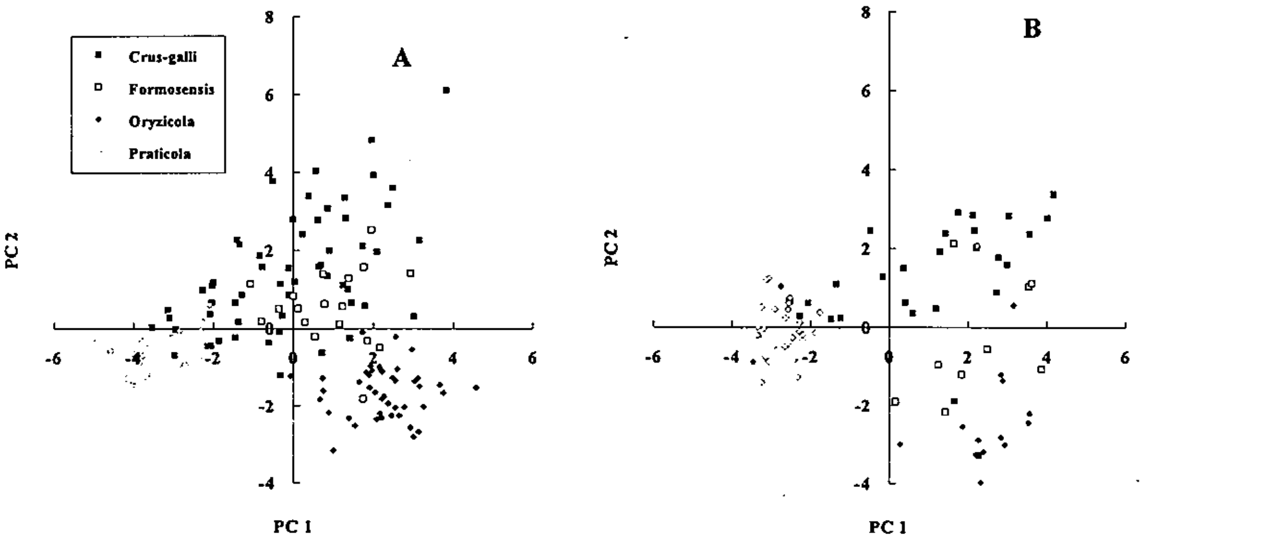


Figure 2. Scatter diagram between the first two principal components of *Echinochloa* weeds at natural habitats (A) and transplanting experiment (B). Weeds were grouped by species and varieties of the genus shown in the legend.

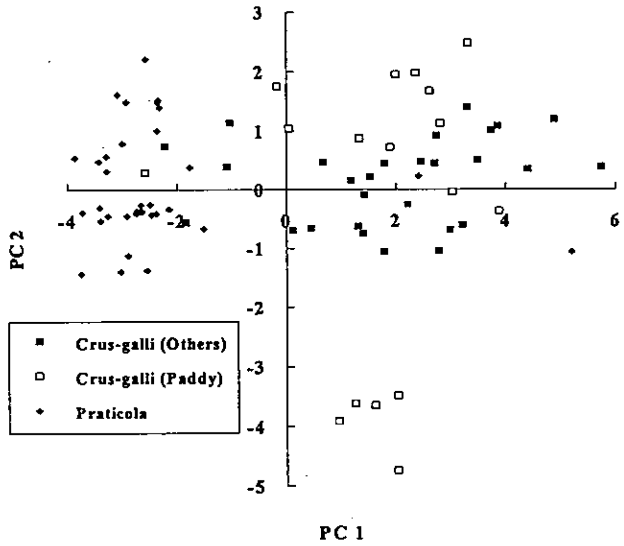


Figure 3. Scattered diagram between the first two principal components of crus-galli and praticola at transplanting experiment. Crus-galli plants originatingfrom rice paddy fields are plotted separately from those from the other habitats.

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# GROWTH HABITAT OF WEEDY RICE AND ITS POSSIBLE CHEMICAL CONTROL

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*Summary*: In recent years, there has been a shift in the rice production system from transplanting to direct-seeding of which dry seeding has gradually been the main method adopted in Korea. This has been accompanied by an increase in weedy rice occurrence particularly in dry seeding. Although there is no difference in nutritional value between weedy rice and rice plant, weedy rice is undesirable because it competes with rice to reduce yield and quality and the grains shatter before maturity. Thus, it is necessary to control weedy rice. Two-hundred and fifty-two weedy rice types were collected at different locations and tested in rice paddy field to determine characteristics of physio-ecology and to screen herbicides for chemical control. Among the tested weedy rice types, culm length mainly ranged from 80 to 110 cm, 35% had awns, 16% had long grains, and 38% had pigment in the grain. Germination of weedy rice was highly inhibited in the treatment of molinate and propanil (Whips) at the concentration of 100 and 200 ppm. In the field, percentage of weedy rice control was relatively low at 45 days after application of herbicides, but molinate and thiobencarb gave higher inhibition in weedy rice germination at early stages compared with the mixture of pyrazosulfuron-ethyl and molinate.

*Keywords*: weedy rice, direct-seeded rice, molinate, propanil, thiobencarb, dry seeding

## INTRODUCTION

*Oryza sativa* L. is the most important staple food crop in Korea. Before introduction of industrialization in 1980, most farmers transplanted rice by hand or machine transplanter, since the farm population was relatively high at 28.4%. However, this had markedly decreased to 10.8% in 1995 and in addition the elderly generation (over 50 years old) was 43.6% in 1994. On the other hand, the younger generation in rural area had migrated to urban areas. Thus, it was necessary to shift rice production systems to the easier method by direct-seeding, but there were severe constraints to acreage enlargement in direct-seeded rice such as poor seedling establishment, weed control, and lodging, particularly under the environment in Korea. Even though direct-seeded rice has all the above problems, farmers especially women prefer to use dry-seeding in direct-seeded rice. As reported in other countries, the United States, Australia, Italy, and Malaysia, with the introduction of direct-seeded rice in Korea, weeds and weedy or red rice have gradually become serious problems, particular with dry-seeding. Its spread is very rapid in the crop season following dry seeding. The objective of this research was to compare morphological characteristics between rice and weedy rice and to determine possible practical strategies for chemical control.

## MATERIALS AND METHODS

*Experiment 1*: A field experiment was conducted to compare 252 different types of weedy rice which had been collected at different locations in the Republic of Korea. Weedy rice was dry-seeded on May 7, 1996. Fertilizer was applied at the rate of 150-70-80 kg/ha ($N-P_2O_5-K_2O$). Nitrogen was applied at 60 kg basal, 90 kg top-dressed at tillering stage and panicle primordia initiation, respectively. Phosphate was applied at 70 kg basal and potassium was applied at 56 kg basal, 24 kg top-dressed at panicle primordia initiation.. Data such as seedling establishment, culm length, shattering, awn character, and grain color were recorded.

*Experiment 2*: The experiment was conducted in the laboratory for preliminary screening of herbicides against weedy rice. Herbicides tested were of a technical grade of thiobencarb, oxidiazon, and propanil. Each herbicide was diluted to give 100 and 200 ppm concentration. Fifty seeds of each weedy rice and rice cultivars (Juanbyeo-Japonica type, and Hwasungbyeo-Japonica type) were sown in 5 replications on autoclaved petri-dishes (5 cm diameter) and 8 mL of each concentration was added. Germinating seeds were counted every day until 10 days after treatment and the final percent control was calculated.

*Experiment 3*: A field experiment was conducted to study control of weedy rice using chemicals: molinate, thiobencarb, pyrazosulfuron-ethyl/molinate, and untreated control. The herbicides were applied at recommended and twice recommended rates at 7 days before seeding rice. Weedy rice was broadcasted prior to the application of chemicals at 3 kg and red rice (Jado, purple-leaf -Japonica type) was seeded to distinguish between weedy rice and purple-leaf rice after seedling establishment. Control percentage and phytotoxicity were evaluated based on a visual rating system and samples of weedy rice were taken at 45 days after treatment.

## RESULTS AND DISCUSSION

*Experiment 1*: Different types of weedy rice tested were highly variable in terms of seedling establishment ranging from 0 to 30% at 30 days after sowing under dry-seeding condition. As shown in Table 1, 48 weedy rice types had 0-10% seedling establishment, 123 types had 10-25% and 79 types had 25-30% seedling establishment.

Table 1. Differences in seedling establishment among weedy rice types at dry seeding condition

| Seedling establishment (%) | Number (and %) weedy rice types |
|---|---|
| 0-10 | 48 (19.2) |
| 10-25 | 123 (49.2) |
| 25-30 | 79 (31.6) |
| Total | 250 (100) |

The seedling establishment of weedy rice was relatively lower than that of cultivated Japonica rice cultivar, Juanbyeo and Hwasungbyeo, which was 25.4-26.2%. This suggests weedy rice has been growing under wild environments and thus variation in seedling establishment was higher and percent germination lower. Meanwhile, culm length was mainly 80-110 cm except for a few weedy rice types (Fig. 1).

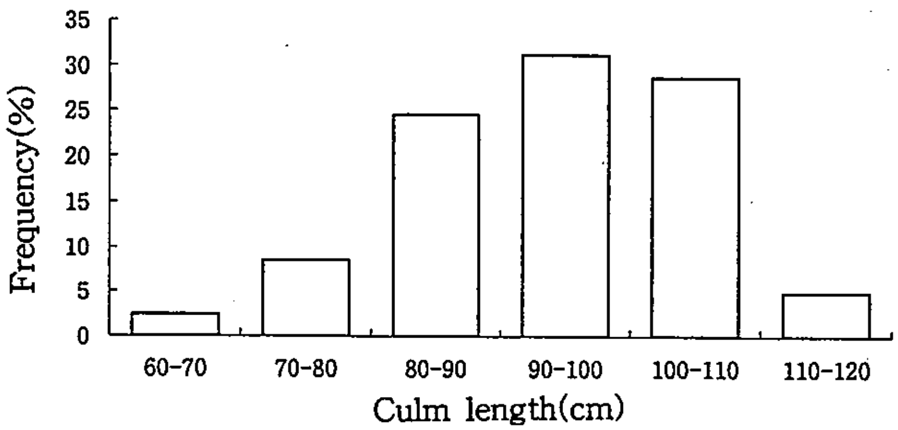


Fig. 1 Frequency of culm length of weedy rice

Results in Fig. 1 implies that most weedy rice had already become adopted and was similar to cultivated rice. The percent shattering was moderately low, but only some weedy rice had very high grain shattering (Fig. 2). We have observed in dry-seeded fields, that most weedy rice easily shatter before ripening or harvesting. Thus, eventhough a few types are involved in this group, high grain shattering in weedy rice types is a much more serious problem.

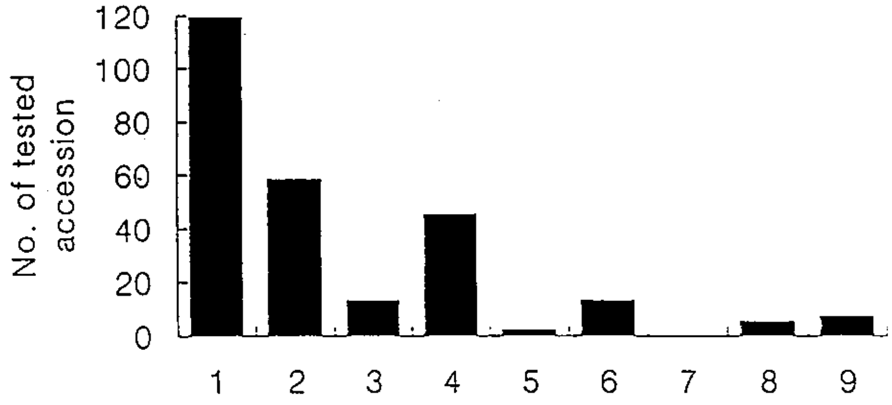


Fig. 2 Degree of grain shattering of weedy rice

Among all weedy rice types 35% had awns and 65% without awns (Fig. 3). About 84% of the weedy rice types had short grains (Fig. 4); and 38% of weedy rice tested had purple grain before harvest (Fig. 5).

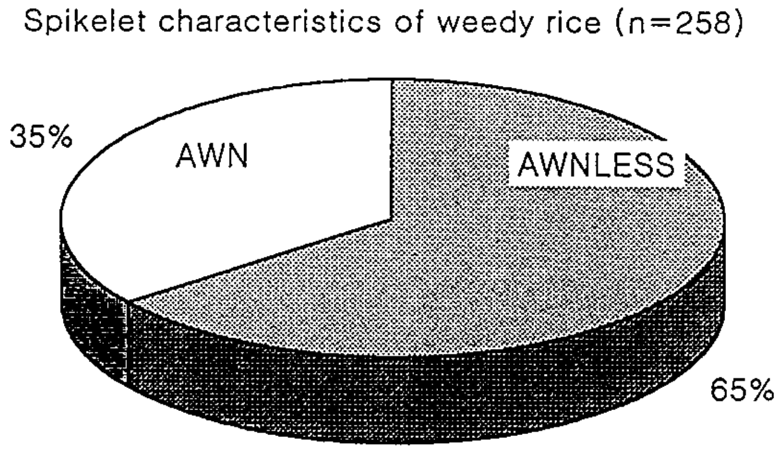


Fig. 3 Proportion of weedy rice types with and without awns.

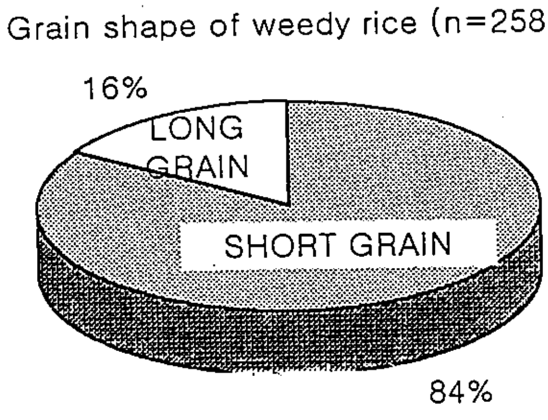


Fig. 4 Proportion of weedy rice with short and long grains.

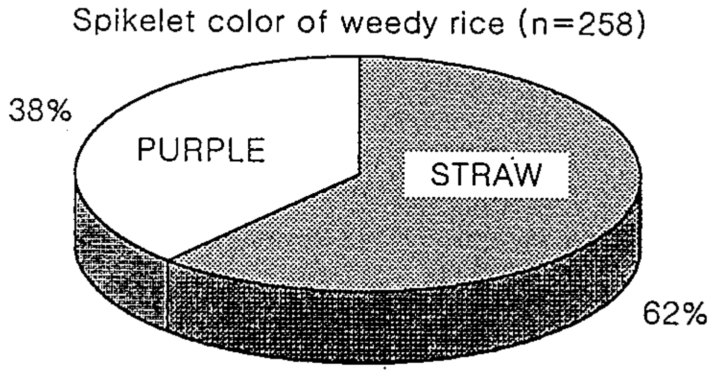


Fig. 5 Proportion of weedy rice with purple or straw grain color.

The results suggest that most weedy rice types were close to the cultivated rice in morpho-physiologically and thus it would be difficult to distinguish between weedy and cultivated rice at the early growing stage. Therefore, weedy rice would be difficult to eradicate in rice fields particularly in dry-seeding.

*Experiment 2.*: There were many publisheded chemical control practices reporting up to 90% weedy rice control: puddling plus thiobencarb (6.7 kg ai/ha), molinate (6.7 kg/ha) with puddling, preplanting herbicide control with glyphosate (2 kg/ha) followed by paraquat (0.754 kg), molinate (4.5 kg/ha) applied pre-sowing incorporated followed by fenoxaprop (0.17 kg) applied at panicle initiation (PI), sequential treatments with molinate (pre-sowing incorporated) followed by sethoxydim (0.11 kg) applied at PI, amidochlor at 1.7 kg applied before heading of weedy or red rice in the field condition. In this laboratory experiment we conducted preliminary screening of herbicides for possible chemical control to kill weedy rice at the germination stage using molinate, thiobencarb, oxidiazon, and propanil (whips). As shown in Table 2, germination of weedy and cultivated rice seeds were totally inhibited at both concentrations of molinate and propanil (whips). Thus these chemicals may be used for weedy rice control under practical field conditions before wet-seeding with a specific time interval.

*Experiment 3*: This trial was conducted in field conditions using the herbicides molinate, thiobencarb, and pyrazosulfuron-ethyl/molinate. There was relatively good weedy rice control at 15 days after treatment, but weedy rice emerged at later stages (Table 3). At 45 days after treatment, the final percent control of weedy rice was highest with molinate at 60 kg product/ha.

Based on these results, we may introduce chemicals to partially control weedy rice in continuous dry-seeding fields. There is no single best method available and thus an integrated strategy to eradicate weedy rice through cultural practices such as water management is important. Also, alternative methods for weedy rice control is to develop rice cultivars like "liberty rice" which is tolerant to non-selective herbicide such as glyphosate and paraquat.

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Table 2. Percent control of weedy rice with the different herbicides in the laboratory

| Herbicide | Concentration (ppm) | Rice cultivar tested | Percent germination | Percent control |
|---|---|---|---|---|
| Untreated control | - | Weedy rice | 98.4 | - |
| | | Juanbyeo | 90.4 | - |
| | | Hwasungbyeo | 98.4 | - |
| Molinate | 100 | Weedy rice | 0 | 100 |
| | | Juanbyeo | 0 | 100 |
| | | Hwasungbyeo | 0 | 100 |
| | 200 | Weedy rice | 0 | 100 |
| | | Juanbyeo | 0 | 100 |
| | | Hwasungbyeo | 0 | 100 |
| Thiobencarb | 100 | Weedy rice | 100 | 0 |
| | | Juanbyeo | 80.0 | 20.0 |
| | | Hwasungbyeo | 82.4 | 17.6 |
| | 200 | Weedy rice | 98.4 | 1.6 |
| | | Juanbyeo | 21.6 | 78.4 |
| | | Hwasungbyeo | 67.2 | 32.8 |
| Oxadiazon (Ronstar) | 100 | Weedy rice | 100 | 0 |
| | | Juanbyeo | 67.2 | 32.8 |
| | | Hwasungbyeo | 84.8 | 15.2 |
| | 200 | Weedy rice | 94.4 | 5.6 |
| | | Juanbyeo | 0.6 | 99.4 |
| | | Hwasungbyeo | 52.0 | 48.0 |
| Propanil (Whips) | 100 | Weedy rice | 0 | 100 |
| | | Juanbyeo | 0 | 100 |
| | | Hwasungbyeo | 0 | 100 |
| | 200 | Weedy rice | 0 | 100 |
| | | Juanbyeo | 0 | 100 |
| | | Hwasungbyeo | 0 | 100 |

Table 3. Percent control of weedy rice in wet-seeded rice in the field

| Herbicide | Application rate (kg/ha) | Weedy rice control (0-9)[1) | | | Percent control |
|---|---|---|---|---|---|
| | | 15 DAT | 30 DAT | 45 DAT | |
| Molinate | 30 | 7 | 7 | 5 | 32 |
| | 60 | 8 | 7 | 7 | 50 |
| Thiobencarb | 30 | 7 | 6 | 5 | 35 |
| | 60 | 8 | 6 | 6 | 39 |
| Pyrazosulfuron-ethyl/Molinate | 30 | 2 | 3 | 3 | 20 |
| Untreated control | - | 0 | 0 | 0 | 0 |

0% - No control, 9-100% control; DAT-Days after treatment

# OCCURRENCE OF WEEDY RICE IN VIETNAM

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*Summary*: An interview survey was carried out in the Long An and Binh Thuan provinces of South Vietnam to investigate weedy rice infestations in ricefields. Five-hundred farmers were selected for the survey during summer - autumn season of 1996. One-hundred and twenty-seven lines of weedy rice were collected, grown and studied in a net-house. Results revealed that weedy rice exists in ricefields (92.5% farmers). The level of weedy rice infestation was high in summer-autumn season as compared to other cropping seasons (93.1%). The respondents said weedy rice comes from degradation of cultivated rice, and contaminated soil and seeds. Farmers' perceptions about some characteristics of weedy rice as compared to cultivated rice are: taller plants (81.9%), weak culm (78.3%), fewer tillers (60.2%) and easy shattering (58.5%). There were 34 weedy rice plants competing with 252 cultivated rice plants in one square meter in Binh Thuan ricefields. Data from 100 lines showed that weedy rice lines had distinctly higher values than cultivated rice for the following characteristics: plant height (112.5 cm/74.3 cm), length of flag leaf (30.8 cm/21.9 cm) and length of panicle (20.1 cm/17.2 cm). The average awn length of weedy rice was 25.7 mm.

*Keywords*: weedy rice, red rice, dry seeding

## INTRODUCTION

Weedy rice is a new pest in rice growing countries of Asia including Vietnam. In temperate region where wild rice does not exist, weedy rice evolved from cultivated rice (2). In tropical areas, weedy rice are progenies of crosses between wild rice and cultivated rice or come from degradation of cultivated rice. The major characteristic of weedy rice is easy shattering. Other characteristics are: taller plants, fewer tillers, and high percentage of red rice in milled rice. Weedy rice competes with cultivated rice for sunlight, water and nutrients resulting in reduction in rice yield. The quality of milled rice is reduced due to contaminated red rice. Weedy rice infestation in ricefields is dangerous because seeds in seed bank increase over time with self regeneration and there is no effective selective herbicide for controlling weedy rice. The existence of weedy rice in Vietnam was detected by scientists from IRRI and CLRRI in a survey conducted during summer - autumn season of 1994 (1). The CLRRI has continued to study weedy rice in Vietnam since then, and in this paper the results of a survey of 500 farmers in Long An and Binh Thuan provinces and studies in a net-house and laboratories are presented.

## MATERIALS AND METHODS

Two-hundred farmers in 11 villages of 4 districts namely Thu Thuan, Tan Tru, Ben Luc and Tan An of Long An province were randomly selected and interviewed on weedy rice infestation and its effect on rice yield in summer - autumn season of 1995. The field survey was conducted during summer - autumn season of 1996 in order to observe the existence of weedy rice in ricefields. In Binh Thuan province, 300 farmers in 5 villages of Bac Binh, Ham Thuan Bac and Tuy Phong districts were interviewed. One hundred lines of weedy rice and 50 samples of cultivated rice were measured directly in the field and in studies in a net-house. Twenty-seven lines collected in Ho Chi Minh city, Long An, Tien Giang and Can Tho during the summer-autumn season of 1995 were tested in CLRRI during summer- autumn season of 1996.

## RESULTS AND DISCUSSION

*Weedy rice infestation*: In Long An during summer-autumn season, 76% farmers practised dry-seeding followed by traditional wet-seeding (20%) and transplanting (3.5%). The corresponding data are 40% and 60%. About 93% farmers said that weedy rice exists in their fields in the summer-autumn season. This percentage is higher in Long An compared to Binh Thuan. In both locations, farmers observed higher weedy rice infestation in the summer-autumn season than other seasons of the year (Table 1).

Table 1. Farmers' perception of weedy rice existence and infestation

| Response | Long An | | Binh Thuan | | Both Locations | |
|---|---|---|---|---|---|---|
| | No. of farmers | % | No. of farmers | % | No. of farmers | % |
| Weedy rice existence | 189 | 98.4 | 266 | 88.7 | 455 | 92.5 |
| High infestation in S-A season | 190 | 99.0 | 268 | 89.3 | 458 | 93.1 |
| Contaminated in rice seed | 84 | 43.8 | 157 | 52.3 | 247 | 50.0 |
| Removed weedy types | 176 | 91.7 | 94 | 31.3 | 270 | 54.9 |

In both locations, 61.8% of farmers stated that the practice of dry-seeding leads to high infestation of weedy rice. In traditional wet-seeding, the percentage was 26.1%. In response to the question of origin of weedy rice, 36.5% stated that it evolved from cultivated rice; the response from farmers in Binh Thuan was much higher (58.7%). Other perceptions on sources of weedy rice were: from soil (32.3%), and mixed with rice seeds (13.7%). Farmers in Long An tend to think that the origin of weedy rice was from the soil (60.7%). Almost all farmers in Long An removed weedy types of rice (91.7%). The most popular method was cutting panicles at flowering stage (52.5%) followed by whole plant removal at booting stage (20.7%) and cutting at ripening stage (20.2%). In contrast, majority of farmers in Binh Thuan do nothing to reduce the weedy rice contamination (58%). Sixty-eight farmers in this province have no idea about removing weedy rice in their fields. In both locations, most farmers (67.7%) said weedy rice caused yield reduction in rice. Fewer farmers (40%) in Binh Thuan province believed that weedy rice reduced rice yields. The reason may be due to different perceptions among farmers in the two sites. The weedy rice existed earlier in Long An and the farmers there perceived weedy rice as a menace compared to those in Binh Thuan province. Yield loss due to weedy rice in dry-seeded rice was 22.5% and 13.8% in Long An and Binh Thuan, respectively.

The Plant Protection Department conducted a survey on 4397 farmers in 128 district of 18 provinces in South Vietnam during the rainy season of 1996. Results showed that majority of farmers practised monoculture (88.15%) and percentage of farmers using herbicides was high (80.68%).

*Farmers perception on weedy rice characteristics*: More than 50% farmers mentioned distinct differences between weedy rice and cultivated rice with respect to the following four parameters: plant height, easy shattering, weak culm and few tillers. Higher percentage of farmers (98.4%) in Long An associated weedy rice with easy shattering, whereas in Binh Thuan, farmers gave more attention to plant height (87.3%). The other distinguishing characteristics with more than 40% farmers response were narrow leaf, awned seed and red milled rice (Table 2).

Table 2. Farmer's perception on weedy rice characteristics

| Weedy rice characteristics | Long An | | Binh Thuan | | Both Locations | |
|---|---|---|---|---|---|---|
| | No. of farmers | % | No. of farmers | % | No. of farmers | % |
| Tall plant | 141 | 73.4 | 262 | 87.3 | 403 | 81.9 |
| Weak culm | 127 | 66.1 | 169 | 56.3 | 296 | 60.2 |
| Few tiller | 154 | 80.2 | 134 | 44.7 | 288 | 58.5 |
| Narrow leaf | 138 | 71.9 | 78 | 26.0 | 216 | 43.9 |
| Awned seed | 75 | 39.1 | 129 | 43.0 | 204 | 41.5 |
| Red milled rice | 137 | 71.4 | 86 | 28.7 | 223 | 45.3 |
| Easy shattering | 189 | 98.4 | 196 | 65.3 | 385 | 78.3 |

*Results of observation on weedy rice lines*: Results of direct measurements on 100 lines existing in Binh Thuan ricefields during the summer-autumn season of 1996 revealed a mean of 34.3 weedy rice plants per square meter as compared to 256.2 cultivated rice plants. The weedy and cultivated rice produced 86.9 and 519.6 tillers per square meter respectively. Weedy rice had higher values than cultivated rice for the following characters: plant height (112.5 cm / 74.3cm), length of flag leaf (30.8 cm/ 21.9 cm), panicle length (20.1 cm / 17.2 cm), and number of filled grains per panicle (53.1 / 34.4). In contrast, characteristics with lower values for weedy rice were width of flag leaf (0.89cm / 0.98cm), and unfilled grain percentage (21.4% / 26.3%). There were similarities in traits such as number of panicles per hill, length of rice seeds, width of seeds, ratio of width and length of seeds and 1000 grain weight. The average awn length was 25.7 mm, whereas cultivated rice varieties have no awn. The standard deviation of many characteristics of weedy rice lines was larger than that of cultivated rice, particularly for number of panicles/hill, awn length, number of filled grains/panicle and unfilled grain percentage. The corresponding coefficients of variation were 58.8, 46.7, 34.3 and 56.6% (Table 3).

Table 3. Characteristics of weedy rice lines and cultivated rice varieties in Binh Thuan

| Characteristic | Weedy rice | | | Cultivated rice | | |
|---|---|---|---|---|---|---|
| | Mean | s.d.* | c.v. (%) | Mean | s.d.* | c.v. (%) |
| No. of panicles/hill | 2.4 | 1.4 | 58.5 | 2.1 | 0.8 | 38.1 |
| Plant height (cm) | 112.5 | 11.9 | 10.6 | 74.3 | 5.8 | 7.8 |
| Length of flag leaf (cm) | 30.8 | 4.5 | 14.6 | 21.9 | 3.2 | 14.6 |
| Width of flag leaf (cm) | 0.89 | 0.2 | 22.5 | 0.98 | 0.1 | 10.2 |
| Panicle length (cm) | 20.1 | 2.6 | 12.9 | 17.2 | 2.0 | 11.6 |
| Awn length (mm) | 25.7 | 1.2 | 46.7 | - | - | - |
| Length of seed (mm) | 8.2 | 0.6 | 7.3 | 8.4 | 0.7 | 8.3 |
| Width of seed (mm) | 2.9 | 0.2 | 6.9 | 2.8 | 0.2 | 7.1 |
| Ratio of width/length | 0.35 | 0.04 | 11.4 | 0.35 | 0.04 | 11.8 |
| Filled grain/panicle | 53.1 | 18.2 | 34.3 | 34.4 | 6.0 | 17.4 |
| Unfilled grain (%) | 21.4 | 12.1 | 56.6 | 26.3 | 11.8 | 44.9 |
| 1000 grain weight (g) | 22.6 | 2.0 | 8.8 | 22.6 | 1.3 | 5.8 |

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# EMERGENCE OF MAJOR WEEDS AND THEIR POPULATION CHANGE IN WET- SEEDED RICE FIELDS OF THE MUDA AREA, PENINSULAR MALAYSIA

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*Summary*: Emergence of major weeds and their population change was investigated from main season 1993/94 to off season 1995 at eleven wet-seeded rice fields in the Muda area. Weeds continued to emerge at high density levels for the four monitoring seasons even when they were well controlled to less than 10 plants/m$^2$ except *Echinochloa* species which showed a distinct decreasing trend. The results suggested that total number of weed emergence was strongly related to seed bank size of individual fields, and a few adult plants produced enough seeds to keep their population density at high levels. Seed longevity of *Echinochloa crus-galli* in soil determined by a pot experiment and its seed production by a field investigation indicated that a high level of control at 97 to 100% would be required to keep its seed population in the soil at low density levels.

*Keywords*: seed bank, emergence, *Echinochloa crus-galli*

## INTRODUCTION

Weed seeds at densities of 712,228 - 930,910 seeds/m$^2$ were recorded in the soil of direct-seeded rice fields in the Muda area (2), indicating that a large amount of weed seeds had accumulated in the soil. Several noxious weeds such as barnyardgrass (*Echinochloa* ssp.), winkle duck-beak (*Ischaemum rugosum* Salisb.) and weedy rice (*Oryza sativa* L.) cannot be easily controlled when they emerge at high density levels. Therefore, proper field management should be practiced to keep weed seed populations in soil at low levels. Azmi *et al.* (1) detected very few viable seeds of *Echinochloa crus-galli* var. *crus-galli* in soil after six cropping seasons after seed incorporation into soil, suggesting that seed longevity of barnyardgrass was shorter than three years in rice fields. We monitored population change of major rice weeds and their seed production in direct-seeded rice fields of the Muda area, Peninsular Malaysia for evaluating seed population change of *Echinochloa crus-galli* in soil in relation to control strategies on a long term basis. The study was conducted from 1992 to 1996 under the Joint Research Program between MARDI, MADA and JIRCAS (3).

## MATERIALS AND METHODS

*Weed population change*: Eleven rice fields located in the same irrigation block of Kampung Alor Senibong, locality B-III, MADA, were selected for investigation of weed population change. Weed population was surveyed from the main season 1993 to the off season 1995. Number of emerged seedlings and adult weed plants were determined according to species. Number of emerged seedlings were counted, before effecting weed control practices, at 10-20 days after seeding (DAS), within five quadrates of 50 x 50 cm, and number of adult plants were determined after rice heading in five 1 x 1 m quadrates.

*Seed production*: Seed production of grass weeds were investigated in heavily infested rice fields in the Muda area. Twenty-seven fields were selected in the main (second) season 1992; seven fields for investigation of *Echinochloa crus-galli* var. *crus-galli*, seven fields for *E. crus-galli* var. *formosensis*, one field for *E. oryzicola*, and twelve fields for *Leptochloa chinensis*. Plant density of each weed species and cultivated rice were determined after rice heading. Ten plants of each grassy weed were sampled before their seeds started to shed, and number of panicles and spikelets were determined. Seed production was estimated from number of spikelets per plants accumulated and plant density data.

*Seed longevity*: Seeds of four grass weeds, *Echinochloa crus-galli* var. *crus-galli*, *E. crus-galli* var. *formosensis*, *E. oryzicola* and *Ischaemum rugosum*, were incorporated into soil, and their emergence and seed longevity were investigated for six seasons (three years) in pot experiments in MARDI Bertam.

*Weed seed population change in soil*: Simulation of weed seed population change in soil was carried out using prescribed parameters and quoted data. Weed seed population is indicated as follows;

$$
\begin{aligned}
SP(t+1) &= SP(t) - Death - Em + Birth - Emigrant + Immigrant \\
&= \underline{SP(t) - Death - Em} + \underline{Birth} \\
&= \underline{Surviving\ seeds} + \underline{Seed\ production} \\
&= \underline{SP(t) \times SV} + \underline{SP(t) \times ER \times (1-CE) \times P}
\end{aligned}
$$

SP = Seed population in soil
ER = Emergence rate (0-1, emergence/seed population)
SV = Seed surviving rate (0-1, ratio to seed population)
CE = Control effect (0-1, adult to emergence)
P = Seed production (seeds/plant)
t = Season

Control effect (CE) is indicated as ratio of number of adult plants to number of emergence, which include mortality not only by weed control practices but by competition and other biological factors, diseases, insects, etc. In the study, several values of CE (88% - 100%) were used for the simulation to evaluate percentage CE value necessary for effective management of seed population in soil.

## RESULTS AND DISCUSSION

*Weed population change*: *Echinochloa* species were well controlled by herbicide and few adult plants, less than eight plants/$m^2$ (mostly 0-3 plants/$m^2$), were observed growing after rice heading (Table 1). Number of young seedlings determined before weed control showed decreasing trend from the main (second) season 1993 to the off (first) season 1995. Distinct difference was observed in emergence of *L. chinensis* among rice fields. High emergence densities of 276-718 plants/$m^2$ were observed in Field No. 2, and lower densities of 0-103 plants/$m^2$ in other fields for the four seasons. *Fimbristylis miliacea* was the most common. It emerged at densities of 54-3074 plants/$m^2$ which were statistically significant between fields. No distinct differences however, was observed between seasons, and trend in weed population was not clear. Emergence in other weeds was also widely variable among fields and differences between seasons was not obvious. Weed population in 11 fields indicated that *Echinochloa* species showed a decreasing trend, although other weeds were at high population levels even when the weeds were well controlled to the density of less than 10 plants/$m^2$ after rice heading, suggesting that a few adult weed plants/$m^2$ produced enough seeds to keep their population at a high level.

*Seed production*: Average number of spikelets were 972/plant in *Echinochloa crus-galli* var. *crus-galli*, 1309/plant in *E. crus-galli* var. *formosensis*, 393/plant in *E. oryzicola* and 1877/plant in *Leptochloa chinensis*. Although one spikelet forms two florets in *Echinochloa* species, only the lower floret is fertile and upper floret is usually sterile. Number of spikelets produced was widely variable from 604 to 1337 spikelets/plant in var. *crus-galli* and 393 to 2660 spikelets/plant in var. *formosensis*. Number of spikelets/plant was also variable in *L. chinensis* from 850 to 4058 spikelets/plant, which was higher than *Echinochloa* species. Five to seven florets/spikelet are formed and a few (2 - 4) of them are usually fertile. It indicates that seed production potential of *L. chinensis* was much higher than both varieties of *Echinochloa crus-galli.*

Table 1 Weed population (plants/m$^2$) in the eleven monitoring fields detected before weed control practices (A) and after rice heading (B)

| Weed species | No. Field | I/1993 B | II/1993 A | II/1993 B | I/1994 A | I/1994 B | II/1994 A | II/1994 B | I/1995 A | I/1995 B |
|---|---|---|---|---|---|---|---|---|---|---|
| *Echinochloa crus-galli* | 1 | 0 | 2 | 0 | 24 | 1 | 0 | 0 | 0 | 0 |
| and | 2 | 2 | 8 | 1 | 0 | 0 | 0 | 2 | 0 | 2 |
| *Echinochloa colona* | 3 | 0 | 80 | 0 | 31 | 0 | 0 | 1 | 0 | 1 |
| | 4 | 0 | 12 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| | 5 | 6 | 0 | 2 | 11 | 2 | 0 | 4 | 0 | 3 |
| | 6 | 1 | 23 | 1 | 19 | 0 | 0 | 2 | 0 | 2 |
| | 7 | 1 | 47 | 0 | 31 | 1 | 0 | 0 | 0 | 0 |
| | 8 | 1 | 44 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| | 9 | 3 | 142 | 8 | 15 | 1 | 0 | 0 | 1 | 1 |
| | 10 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 11 | 0 | 33 | 2 | 0 | 0 | 0 | 2 | 0 | 1 |
| *Leptochloa chinensis* | 1 | 0 | 0 | 0 | 8 | 0 | 8 | 0 | 0 | 0 |
| | 2 | 0 | 15 | 1 | 21 | 0 | 23 | 0 | 76 | 1 |
| | 3 | 29 | 443 | 27 | 276 | 6 | 445 | 9 | 718 | 7 |
| | 4 | 0 | 7 | 0 | 18 | 0 | 6 | 0 | 7 | 1 |
| | 5 | 0 | 3 | 2 | 60 | 1 | 95 | 3 | 13 | 3 |
| | 6 | 0 | 2 | 0 | 103 | 0 | 29 | 1 | 33 | 1 |
| | 7 | 0 | 0 | 0 | 82 | 0 | 73 | 0 | 14 | 1 |
| | 8 | 1 | 2 | 0 | 0 | 0 | 14 | 2 | 24 | 3 |
| | 9 | 2 | 34 | 6 | 50 | 0 | 14 | 0 | 2 | 0 |
| | 10 | 0 | 5 | 0 | 6 | 0 | 7 | 0 | 11 | 0 |
| | 11 | 0 | 0 | 0 | 9 | 0 | 14 | 0 | 0 | 0 |
| *Fimbristylis miliacea* | 1 | 0 | 139 | 27 | 309 | 4 | 320 | 4 | 434 | 3 |
| | 2 | 21 | 1,387 | 69 | 2,384 | 12 | 702 | 0 | 1,831 | 2 |
| | 3 | 12 | 754 | 47 | 1,266 | 13 | 1,076 | 4 | 1,325 | 4 |
| | 4 | 61 | 3,074 | 29 | 1,733 | 6 | 308 | 1 | 722 | 3 |
| | 5 | 84 | 662 | 30 | 1,364 | 25 | 1,620 | 10 | 1,106 | 6 |
| | 6 | 29 | 1,556 | 73 | 1,381 | 14 | 129 | 2 | 1,566 | 2 |
| | 7 | 10 | 1,702 | 11 | 2,023 | 13 | 422 | 15 | 741 | 9 |
| | 8 | 50 | 570 | 29 | 990 | 25 | 262 | 6 | 923 | 5 |
| | 9 | 1 | 441 | 8 | 512 | 5 | 1,500 | 0 | 1,517 | 1 |
| | 10 | 2 | 250 | 7 | 284 | 4 | 634 | 4 | 529 | 3 |
| | 11 | 3 | 260 | 12 | 147 | 1 | 76 | 1 | 54 | 2 |
| other sedges total | 1 | 12 | 146 | 9 | 290 | 59 | 347 | 12 | 290 | 8 |
| | 2 | 22 | 78 | 22 | 245 | 39 | 923 | 6 | 226 | 6 |
| | 3 | 4 | 38 | 6 | 238 | 5 | 601 | 8 | 418 | 11 |
| | 4 | 11 | 150 | 12 | 246 | 7 | 144 | 5 | 360 | 4 |
| | 5 | 47 | 50 | 6 | 290 | 5 | 163 | 2 | 14 | 1 |
| | 6 | 2 | 18 | 16 | 95 | 4 | 119 | 2 | 28 | 2 |
| | 7 | 2 | 146 | 2 | 334 | 4 | 458 | 3 | 324 | 3 |
| | 8 | 3 | 59 | 21 | 469 | 25 | 68 | 4 | 94 | 2 |
| | 9 | 5 | 2 | 0 | 84 | 3 | 75 | 4 | 88 | 2 |
| | 10 | 1 | 10 | 2 | 78 | 6 | 61 | 4 | 184 | 5 |
| | 11 | 2 | 27 | 2 | 39 | 2 | 23 | 1 | 46 | 4 |
| *Monochoria vaginalis* | 1 | 0 | 55 | 7 | 93 | 0 | 62 | 0 | 134 | 0 |
| and | 2 | 36 | 46 | 8 | 599 | 0 | 442 | 8 | 126 | 4 |
| *Sagittaria guyanensis* | 3 | 0 | 2 | 9 | 0 | 1 | 50 | 8 | 46 | 4 |
| | 4 | 10 | 187 | 16 | 338 | 6 | 118 | 4 | 54 | 3 |
| | 5 | 16 | 44 | 28 | 105 | 1 | 6 | 0 | 6 | 0 |
| | 6 | 11 | 41 | 5 | 8 | 4 | 21 | 1 | 34 | 2 |
| | 7 | 0 | 0 | 0 | 2 | 0 | 20 | 0 | 5 | 0 |
| | 8 | 3 | 17 | 11 | 38 | 1 | 27 | 11 | 40 | 10 |
| | 9 | 10 | 14 | 9 | 17 | 0 | 6 | 0 | 45 | 0 |
| | 10 | 3 | 3 | 2 | 0 | 4 | 6 | 0 | 0 | 2 |
| | 11 | 0 | 12 | 11 | 0 | 1 | 9 | 5 | 6 | 5 |
| *Ludwigia hyssopifolia* | 1 | 0 | 40 | 3 | 440 | 0 | 222 | 0 | 240 | 0 |
| | 2 | 5 | 46 | 17 | 82 | 5 | 725 | 0 | 813 | 0 |
| | 3 | 0 | 6 | 21 | 254 | 10 | 437 | 0 | 423 | 1 |
| | 4 | 9 | 51 | 0 | 81 | 4 | 62 | 1 | 59 | 2 |
| | 5 | 80 | 972 | 17 | 288 | 0 | 214 | 0 | 60 | 1 |
| | 6 | 7 | 70 | 20 | 136 | 12 | 135 | 0 | 136 | 0 |
| | 7 | 0 | 622 | 0 | 262 | 0 | 301 | 1 | 202 | 2 |
| | 8 | 17 | 362 | 10 | 169 | 5 | 102 | 2 | 138 | 3 |
| | 9 | 0 | 26 | 4 | 286 | 2 | 56 | 0 | 102 | 1 |
| | 10 | 1 | 2 | 2 | 95 | 1 | 105 | 3 | 122 | 3 |
| | 11 | 1 | 79 | 3 | 83 | 0 | 204 | 5 | 319 | 4 |

*Seed longevity*: Emergence data showed exponential decrease in all plots, although initial numbers emerging varied between plots, indicating that emergence decreased at a constant rate seasonally (Fig. 1), indicating also that viable seed population also decreased at a constant surviving rate as follows;.

$$SP(t) - D - Em = SP(t) \times SV$$

SP = Seed population
D = Death
Em = Emergence
SV = Seed surviving rate

Distinct differences was observed for critical parameters in the exponential equation [$N_t = N_1 \times e^{-b(t-1)}$] with respect to species, and different water management. Emergence decreasing rate (parameter b) of *E. crus-galli* var. *crus-galli* was higher than that of *E. crus-galli* var. *formosensis* and *E. oryzicola*, indicating that seed longevity of *E. crus-galli* var. *crus-galli* was shorter than of the other *Echinochloa* species. Higher decreasing rate was observed in *Ischaemum rugosum* in flooded plots, indicating that seed longevity of the weed was much shorter in flooded condition compared to terrestrial condition. Seed surviving rate in soil (SV) was estimated by the decreasing trend in emergence or $e^{-b}$.

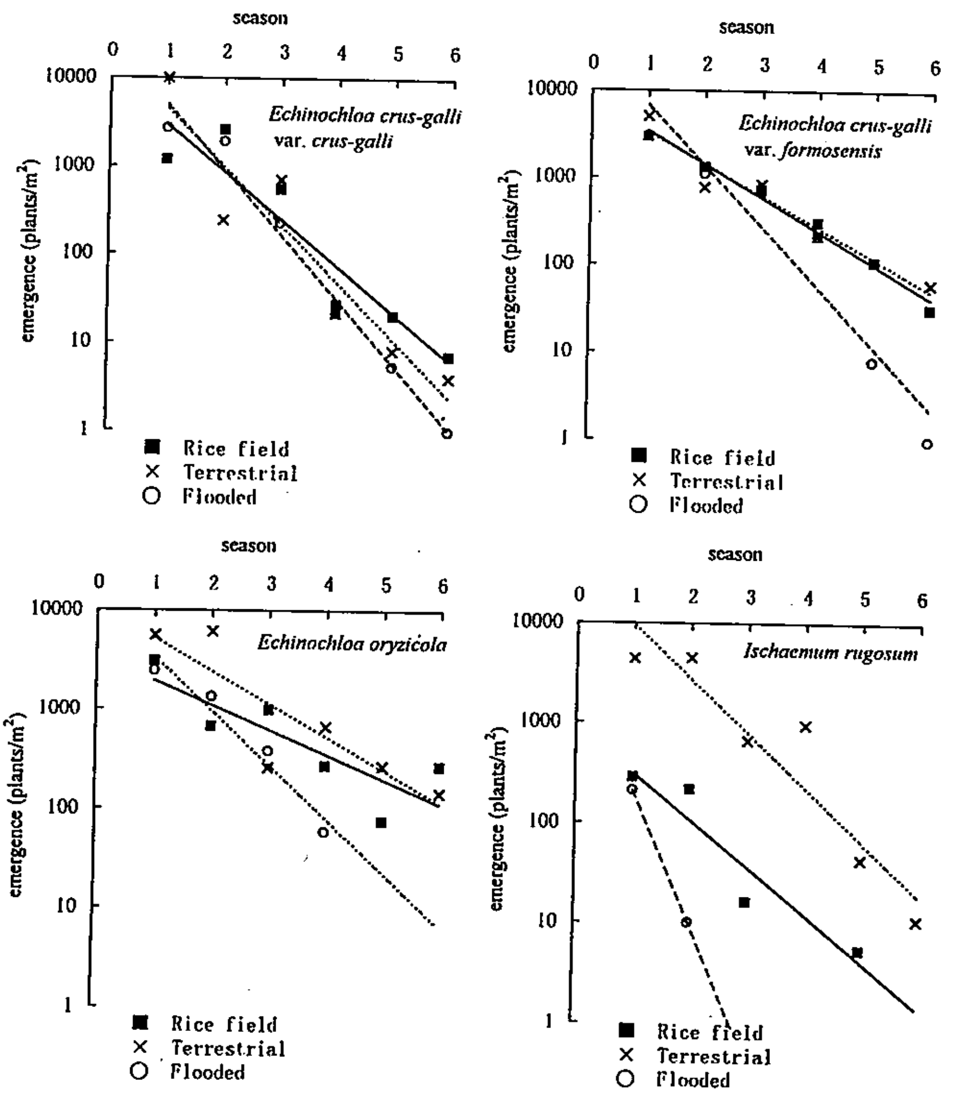


Fig. 1. Decrease in total emergence of four grass weeds during six seasons (three years) after seed incorporation into soil

*Weed seed population change in soil*: Results of the simulation suggested that seed population of *E. crus-galli* var. *crus-galli* increases when CE value was lower than 97% (Fig. 2), while *E. crus-galli* var. *formosensis* increased when CE value is lower than 98%, indicating that a high level of control is necessary to keep the seed population in the soil at low levels. Weedy rice (shorter longevity seeds and lower seed productivity compared to *E. crus-galli*) was also simulated, and the results indicated that lower than 92% of CE value would allow the weedy rice to increase the seed population in the soil. The simulation was conducted using several data reported elsewhere since ecological information on rice weeds (weed germination, emergence, mortality and seed production) in direct seeded rice in Malaysia and their relationship with environmental and biological conditions was limited. More detailed information on weed ecology is needed for a complete study of the weed seed bank.

*Echochloa crus-galli* var. crus-galli

| | |
|---|---|
| SP = Seed population in soil | SP(1) = 100 (initial population) |
| ER = Emergence rate | ER = 0.03 |
| SV = Seed surviving rste | SV = 0.2 |
| CE = Contro; Effect | (indicated in the figure) |
| P = Seed production | P = 1000 seeds/plant |

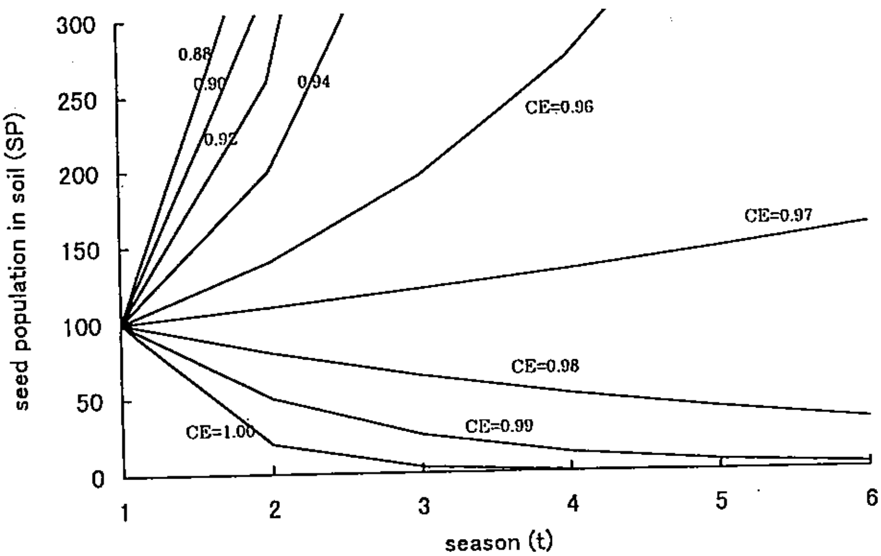


Fig. 2 Simulation of seed population change of *Echinochloa crus-galli* var. *crus-galli*

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# WEED POPULATIONS IN DIRECT-SEEDED RICE AS AFFECTED BY SEEDING RATES

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*Summary*: Field trials were carried out at MARDI Rice Research Centre, Bertam, Penang to investigate the effect of increasing seed rates on weed suppression in wet-seeded rice (DSR). Seeding rates from 20 to 200 kg/ha were evaluated from March 1995 to February 1996 with different weed pressure i.e. DSR against various weed species (off season 1995), DSR against *Echinochloa crus-galli* (main season 1995/96) and padi angin (weedy rice) (main season 1995/96). Higher seeding rates were observed to have high crop density at 25 days after sowing. Subsequently, plant compensation at lower seeding rates resulted in non-significant effect on number of plants/m$^2$. *Monochoria vaginalis* was significantly suppressed by increasing seeding rates in the DSR experiment against various weed species. Furthermore, *Echinochloa crus-galli* was also significantly suppressed at high seeding rates under heavy infestion situation. On the other hand, there was no significant effect of increasing seeding rates on padi angin population.

*Keywords*: rice seeding rates, direct-seeded rice

## INTRODUCTION

In Malaysia, seeding rates used by some farmers in direct-seeded rice are generally high (>100 kg/ha) to help reduce weed infestation, to compensate for damage by rats and birds, to compensate for poor stand establishment, to avoid having to fill gaps in the field and to partially overcome the adverse effects of herbicides. In the Philippines, rates of 150 kg/ha are not uncommon and rates as high as 400 kg/ha have been used (5). Even though the use of such high rates may not be economical, the farmer is reluctant to use lower rates because of increased problems with weeds. In addition, broad-leaved weeds were most affected by the increase in seeding rates and sedges the least affected. For dry-seeded rice, increasing the seed rate had little influence on weed suppression probably because of intense weed pressure (6). Furthermore, Moody (6) reported that in trials conducted in the Philippines, weed weight was affected by cultivar grown, row spacing or seeding rates up to 160 kg/ha. The objective of this study was to determine the effect of increasing seeding rates on weed species population in direct-seeded rice under Malaysian ricefield conditions.

## MATERIALS AND METHODS

Three experiments were conducted in MARDI Rice Research Centre, Bertam in the main season 1995/96 and off season 1995/96 under following conditions: seeding rates against various weed species (off season 1995); seeding rates against *E. crus-galli* (main season 1995/96); and seeding rates against *padi angin* (weedy rice)(main season 1995/96).

Pregerminated MR 84 rice seeds were broadcast onto the puddled soil at different seeding rates i.e. 20, 40, 60, 80, 100, 120, 140, 160, 180 and 200 kg/ha. The experimental design was a randomised complete block with six replications. All plots (5x5 m) were flooded at 7 days after sowing (DAS) and 5 to 10 cm water was maintained for the duration of crop growth. A total of 100:30:30 kg/ha NPK was applied to the rice crop. Basal fertilizer of 40:30:30 kg/ha NPK was broadcasted at 15 DAS. The remaining nitrogen was applied in two equal top-dressings at 30 and 55 DAS. Recommended insecticides were applied as necessary to control insect pests. Weeds were sampled outside 4x4 m plot area from four 50x50 cm quadrats/plot at 60 DAS. The weeds were classified by species and groups. Dry weights were recorded after oven drying for 24 h at 80°C. Crop density in Experiment 1 was taken at 25 DAS using 0.25x0.25 m quadrat. Density of crop and *padi angin* were also taken at harvest for experiment 3. Plant height and tiller count were made at 30, 60, 90 DAS and at harvest. Yield data were obtained from the centre 4x4 m area of each plot. Grain yield samples were converted to kilogram per hectare at 14% moisture. Data were analysed by analysis of variance (ANOVA).

## RESULTS AND DISCUSSION

In experiment 1, increasing seeding rates in DSR against various weed species did not affect plant height at 30, 60, 90 DAS and at harvest (Table 1). However, increasing seeding rates were found to significantly increased number of tillers/0.25m x 0.25m at 30 and 90 DAS. Crop density at 25 DAS were also significantly increased by increasing seed rates. High seeding rate i.e. 200 kg/ha resulted in the highest crop density at 545 plants/$m^2$ compared to the lowest seeding rate i.e. 20 kg/ha at 97.8 plants/$m^2$.

There was a significant decrease in total weed weight as the seeding rate increased from 20 kg/ha to 200 kg/ha (Table 2) whereby there was a significant negative correlation between total weed dry weight and seeding rates ($y = 42.1 - 0.14x$, $r = - 0.81$)). The highest seeding rate (200 kg/ha) recorded lower total weed dry weight at 17.1 g/$m^2$ compared to 44.2 g/$m^2$ at low seeding rate (20 kg/ha). This relationship was related to suppression of *M. vaginalis* at high seeding rates as shown by the significant negative correlation between its dry weight and seeding rates ($y = 3.32 - 0.11x$, $r = - 0.82$). This study indicated that high seeding rates were beneficial in suppressing *M. vaginalis* but not other broad-leaved weeds like *L. hyssopifolia* and *B. rotundifolia*. High seeding rates also did not suppress sedges and grasses. Thus, high seeding rate can only partially compensate for poor weed control.

In experiment 2, increasing seeding rate in a field heavily infested by *E. crus-galli* did not significantly affect plant height at 30, 60 and 90 DAS except at harvest (Table 3). Low seeding rates i.e. 20 and 40 kg/ha significantly increased plant height at harvest compared to high seeding rates i.e. 60 kg/ha onwards. Plant height recorded was 86.9 cm at seeding rate of 20 kg/ha compared to 79.6 cm at 160 kg/ha. Number of tillers produced/$m^2$ were also not affected by seeding rates except at 60 DAS. Generally, high seeding rates increased number of tillers produced at 60 DAS. At 20 kg/ha, number of tillers was 17.1/$m^2$ compared to 22.2/$m^2$ at 180 kg/ha. Consequently, due to plant compensation at low seeding rates, there were no significant effect of seeding rates on number of tillers/$m^2$ at 90 DAS onwards.

Increasing seeding rates seemed to suppress *E. crus-galli* at 60 DAS as shown by the significant negative correlation between seeding rates and dry weight ($y = 463.4 - 1.34x$, $r = -0.81$). Lowest seeding rate i.e. 20 kg/ha recorded 510.5g/$m^2$ dry weight of *E. crus-galli* compared to 232.3 g/$m^2$ at 200 kg/ha. The results indicated that under heavy infestation of *E. crus-galli*, high seeding rate is useful to suppress this weed in direct-seeded rice under unweeded situations.

In experiment 3, increasing seeding rates (i.e. 20 to 200 kg/ha) showed no significant effect on plant height of direct-seeded rice in a field heavily infested by *padi angin* (Table 4). However, number of tillers (per 0.25x0.25 m) produced at 30 DAS were significantly affected by increasing seeding rates. At 20 kg/ha, number of tillers (per 0.25x0.25 m) produced was 12.2 compared to 14.2 at 200 kg/ha seeding rate. Subsequently, due to plant compensation at lower seeding rates, there were no effect of increasing seeding rates on tiller production after 60 DAS. Furthermore, density of *padi angin* at harvest was not significantly suppressed by increasing seeding rates.

Normally low plant density and the presence of gaps encourages the growth of weeds. Such a stand will, in many cultivars, result in less uniform ripening and poor grain quality (7). On the other hand, too dense a stand should be avoided because it tends to increase lodging, prevents the full benefit of nitrogen application, increases the chances of rat damage and pest outbreak. Results from this study showed that, in rice areas with *M. vaginalis* or *E. crus-galli* problem, high seeding rate can compensate partly for poor weed control. However, there was no significant effect on grain yields in unweeded plots as a result of increased seeding rates (Table 5). Even though the yields were not significantly affected, there is a possibility plots heavily infested by these weeds will increase the size of their seed bank which will pose problems in subsequent seasons. Furthermore, the study was conducted under normal fertilization and the effect of increasing seeding rates may be different under different fertilizer rates.

This study did not indicate optimum seed rate for unweeded situations. Therefore, any seed rate can be used in direct-seeded rice depending on weed control practices used. Low seeding rates can be used because of plant compensation at later growth stages provided weed control is carried out. The best solution is to use seed rate at 60 to 80 kg/ha. However, farmers often sow at a very high rate exceeding 80 kg/ha for fear of not getting good crop establishment (1). Hiraoka and Ho (4) reported farmers in Muda area used seeding rates ranging from as low as 37 kg/ha to as high as 100 kg/ha. High seeding rate does not contribute to yield increase but was practised as an insurance against establishment uncertainty. In addition, Guyer and Quadranti (3) noted that higher seeding rates would be beneficial if no weed control is planned or only partial weed control is expected. Subsequently, it is not necessary to use high seeding rates to suppress weeds in direct-seeded rice if a herbicide that is effective in controlling weeds is used (2). Furthermore, if weeds cannot be properly controlled, use of high seeding rate will be beneficial in suppressing certain weed species. Normally, 60 kg/ha seed is recommended for broadcasting culture in the Muda area, but in practice farmers usually exceed recommendation (8). Nonetheless, at a seeding rate of even less than 60 kg/ha, a yield level of 5 t/ha or even higher can be achieved.

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Table 1. Effect of increasing seed rates on plant height and number of tillers of direct seeded rice, (off season 1995, MARDI Bertam, Seberang Perai.)

| Seed rate (kg/ha) | Plant height (cm) | | | | No. of tillers/0.25m x 0.25m | | | | Crop density /m$^2$ at 25 DAS |
|---|---|---|---|---|---|---|---|---|---|
| | 30 DAS | 60 DAS | 90 DAS | At harvest | 30 DAS | 60 DAS | 90 DAS | At harvest | |
| 20 | 53.1 | 81.0 | 95.8 | 98.4 | 13.0 | 13.1 | 15.8 | 12.0 | 97.8 |
| 40 | 56.3 | 80.8 | 94.6 | 97.4 | 15.0 | 13.9 | 16.7 | 11.8 | 156.5 |
| 60 | 56.2 | 82.8 | 91.4 | 100.3 | 16.5 | 15.5 | 17.0 | 12.9 | 157.8 |
| 80 | 55.5 | 83.7 | 94.1 | 97.9 | 17.8 | 18.2 | 17.8 | 12.2 | 252.7 |
| 100 | 59.4 | 85.3 | 93.8 | 94.1 | 17.2 | 16.0 | 17.8 | 12.5 | 343.8 |
| 120 | 54.6 | 82.7 | 91.5 | 97.2 | 20.6 | 19.2 | 20.0 | 12.2 | 337.2 |
| 140 | 57.4 | 81.5 | 91.2 | 95.4 | 19.1 | 17.2 | 18.6 | 12.0 | 324.0 |
| 160 | 57.2 | 81.6 | 94.4 | 94.8 | 20.6 | 20.9 | 19.6 | 13.4 | 408.8 |
| 180 | 57.9 | 79.8 | 92.7 | 93.1 | 18.9 | 17.2 | 17.6 | 13.0 | 410.8 |
| 200 | 56.8 | 79.7 | 91.5 | 96.5 | 26.7 | 19.9 | 19.8 | 12.9 | 545.0 |
| LSD (5 %) | NS | NS | NS | NS | 5.85 | 4.55 | NS | NS | 183.9 |

DAS = days after sowing

Table 2. Effect of increasing seed rates on weed dry weight at 60 days after sowing and yield of direct seeded rice, (main season 1995/96, MARDI Seberang Perai).

| Seed rate (kg/ha) | Weed dry weight (g/m$^2$)* | | | | Total weed weight (g/m$^2$) |
|---|---|---|---|---|---|
| | *Ludwigia hyssopifolia* | *Monochoria vaginalis* | *Bacopa rotundifolia* | Grass & Sedge | |
| 20 | 5.5 | 30.3 | 0.6 | 7.8 | 44.2 |
| 40 | 5.3 | 22.8 | 5.0 | 2.5 | 35.6 |
| 60 | 4.5 | 24.0 | 8.7 | 2.3 | 39.5 |
| 80 | 12.2 | 13.3 | 0.2 | 5.0 | 30.7 |
| 100 | 5.7 | 8.8 | 0.8 | 0.53 | 15.8 |
| 120 | 5.5 | 19.5 | 0.5 | 6.5 | 32.0 |
| 140 | 5.7 | 6.5 | 1.5 | 4.0 | 17.7 |
| 160 | 3.8 | 12.5 | 6.3 | 2.1 | 23.7 |
| 180 | 5.0 | 9.6 | 2.3 | 0.8 | 17.7 |
| 200 | 7.6 | 7.5 | 0.83 | 1.2 | 17.1 |
| LSD (5%) | - | - | - | - | 16.9 |

*average of six replicates

Table 3. Effect of increasing seed rates on plant height and number of tillers of direct seeded rice, with *E. crus-galli* as major weed, (main season 1995/96, MARDI Bertam; Seberang Perai.)

| Seed rate | Plant height (cm) | | | | No. of tillers/0.25m x 0.25m | | | | Dry weight of E. Cr./m² |
|---|---|---|---|---|---|---|---|---|---|
| (kg/ha) | 30 DAS | 60 DAS | 90 DAS | At harvest | 30 DAS | 60 DAS | 90 DAS | At harvest | at 60 DAS |
| 20 | 48.4 | 82.6 | 92.0 | 86.9 | 10.4 | 17.1 | 17.8 | 19.4 | 510.5 |
| 40 | 48.6 | 83.0 | 90.8 | 86.0 | 10.2 | 17.4 | 18.9 | 19.2 | 441.1 |
| 60 | 55.4 | 80.9 | 89.1 | 82.7 | 11.0 | 18.1 | 20.6 | 21.4 | 371.1 |
| 80 | 51.0 | 82.8 | 90.7 | 83.9 | 10.9 | 18.6 | 20.5 | 21.0 | 263.8 |
| 100 | 49.7 | 77.9 | 87.6 | 81.0 | 10.8 | 18.5 | 20.0 | 22.3 | 300.5 |
| 120 | 50.0 | 82.3 | 89.4 | 83.8 | 10.9 | 20.2 | 20.1 | 21.0 | 324.9 |
| 140 | 50.2 | 82.2 | 89.8 | 82.2 | 12.3 | 19.5 | 21.1 | 22.1 | 176.5 |
| 160 | 52.3 | 78.0 | 89.7 | 79.6 | 11.5 | 20.0 | 20.7 | 21.4 | 258.9 |
| 180 | 63.3 | 81.1 | 89.5 | 80.0 | 12.7 | 22.2 | 21.3 | 23.6 | 281.6 |
| 200 | 50.4 | 79.8 | 90.6 | 81.0 | 13.1 | 20.9 | 21.6 | 22.8 | 232.3 |
| LSD (5 %) | NS | NS | NS | 4.43 | NS | 2.95 | NS | NS | 91.9 |

DAS = days after sowing, E. Cr = *E. crus-galli*

Table 4. Effect of increasing seed rates on plant height and number of tillers of direct seeded rice (MR 84) where *padi angin* was the major weed, (main season 1995/96, MARDI Bertam, Seberang Perai.)

| Seed rate | Plant height (cm) | | | | No. of tillers/0.25m x 0.25m | | | | Plant density* | |
|---|---|---|---|---|---|---|---|---|---|---|
| (kg/ha) | 30 DAS | 60 DAS | 90 DAS | At harvest | 30 DAS | 60 DAS | 90 DAS | At harvest | DSR | PA |
| 20 | 52.7 | 84.4 | 94.7 | 86.8 | 12.2 | 15.3 | 14.3 | 12.0 | 15.8 | 17.3 |
| 40 | 51.5 | 82.3 | 88.4 | 86.1 | 13.2 | 14.8 | 14.0 | 12.6 | 13.3 | 20.3 |
| 60 | 53.0 | 80.0 | 91.0 | 86.4 | 11.6 | 16.2 | 14.9 | 12.2 | 14.8 | 20.4 |
| 80 | 52.0 | 78.1 | 91.7 | 85.6 | 14.7 | 17.3 | 16.7 | 14.6 | 17.1 | 16.5 |
| 100 | 53.0 | 79.2 | 94.6 | 88.4 | 13.5 | 18.1 | 17.6 | 16.0 | 16.1 | 20.7 |
| 120 | 52.5 | 79.4 | 92.6 | 84.1 | 13.8 | 17.3 | 15.2 | 13.6 | 18.0 | 19.4 |
| 140 | 52.3 | 79.7 | 86.9 | 85.0 | 13.4 | 17.3 | 16.2 | 15.1 | 16.0 | 14.7 |
| 160 | 52.0 | 80.9 | 94.5 | 86.1 | 13.9 | 17.5 | 16.2 | 13.5 | 15.3 | 17.8 |
| 180 | 56.9 | 77.8 | 92.0 | 83.3 | 15.2 | 19.4 | 16.3 | 13.9 | 19.3 | 16.1 |
| 200 | 52.5 | 78.3 | 92.6 | 86.0 | 14.2 | 16.8 | 16.1 | 13.8 | 17.2 | 15.5 |
| LSD (5 %) | NS | NS | NS | Ns | 1.82 | NS | NS | Ns | NS | NS |

DAS = days after sowing, DSR = direct seeded rice; * = Plant density - no. of plants/m²
DSR = direct seeded rice; PA = *padi angin*

Table 5. Seeding rates and yield of direct seeded rice under different weed species

| Seed rate (kg/ha) | Seeding rate against various weed species | Seeding rate against *Echinochloa crus-galli* | Seeding rate against *padi angin* |
|---|---|---|---|
| 20 | 1137 | 2506 | 492 |
| 40 | 1073 | 2923 | 508 |
| 60 | 987 | 2647 | 592 |
| 80 | 1216 | 2873 | 1088 |
| 100 | 957 | 2557 | 1000 |
| 120 | 1280 | 3020 | 856 |
| 140 | 1013 | 2690 | 992 |
| 160 | 973 | 2723 | 868 |
| 180 | 857 | 3153 | 1060 |
| 200 | 1173 | 2943 | 1216 |

# RESPONSES OF COMPETITIVE AND NONCOMPETITIVE UPLAND RICE CULTIVARS TO WEED COMPETITION

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*Summary:* Two competitive and two noncompetitive cultivars of rice were selected to determine their growth responses to weeds in the 1995 and 1996 wet seasons. Competitive cultivars tended to have low reductions in height and tiller number due to weed competition when compared with noncompetitive cultivars. Dry weight and leaf area were the rice characters most affected by competition. Grain yield was not significantly different between rice cultivars when plots were not weeded. When plots were weeded, competitive cultivars generally yielded higher than noncompetitive cultivars in both years. However, there was no evidence from this study that competitive cultivars or inter-row cultivation could substitute for hand weeding.

*Keywords*: weed competition, rice cultivar, competitive ability

## INTRODUCTION

The use of competitive rice cultivars and good crop husbandry can minimize weed control inputs needed to achieve optimum yields. Competitive cultivars may provide the practical equivalent of one or two hand weedings (3) and reduce costs of weed control (11).

Competitive ability of rice is measured in terms of weed effects on yield and other plant characters that contribute to yield. Reduction in height, tiller number, leaf area and dry weight can result in low yield (6). Fischer *et al.* (2) reported that height, tillers, leaf area and dry weight of different rices were reduced 29-53% by competition from *Brachiaria brizantha* (Hochst. ex A.Rich) Stapf. during the first 30 days after emergence (DAE) at densities of 200 rice plants and 200 weeds/m$^2$. The growth of *B. brizantha* was also reduced by 31-53%.

An understanding of how rice cultivars respond to weed competition is important in the development of appropriate cultural practices to shift the competitive advantage from weeds toward the rice crop. This experiment was conducted to determine the growth and yield responses of competitive and non-competitive rice cultivars to weed competition.

## MATERIALS AND METHODS

Two competitive (Vandana and Aus 257) and two noncompetitive (IRAT169F 10/6 (1995) /IRAT216 (1996) and P5589-1-1-3P) rice cultivars were selected for comparison based on findings of previous studies (5, 6).

They were composed of two experiments conducted from June to October in the 1995 and 1996 wet seasons in a farmer's field in Tanauan, Batangas, Philippines. The field was plowed once, disc-harrowed twice, and cultivated twice by spike-toothed harrow to prepare a fine, weed-free seedbed. Furrows spaced 25 cm apart were made using a wooden furrower. Plots measuring 7 x 6 m (1995) and 2.5 x 5 m (1996) were laid out in a split-plot design with four replications. Weeding levels were assigned to the main plots and cultivars to the subplots. In 1995 the weeding levels were no weeding, hand weeding at 21 DAE, and hand weeding at 7 and 35 DAE. In 1996, the hand weeding at 21 DAE treatment was replaced with inter-row cultivation using a furrower at 7 and 35 DAE. Weeding treatments were selected to provide high, medium and low weed pressure.

Rice seeds were sown in furrows at 100 kg/ha in 1995 and 50 seeds/m in 1996. Forty kilograms of N, $P_2O_5$ and $K_2O$ per hectare were broadcast after seeding in 1995, and at 14 DAE in 1996, and then covered with soil. An additional 40 kg N/ha was applied at 49 DAE in both years.

Plant height, tiller number, leaf area and dry weight of rice and density and dry weight of weeds were measured at 2-week intervals until 8 weeks after emergence from two 50 x 50 cm quadrats in each plot using a block sampling technique (4). Plant samples were washed, measured for selected parameters, dried at 80°C for 48 h, then weighed. Yield was taken at the center of each plot from a 5 x 2 m quadrat in 1995 and 3 x 1 m' in 1996, and converted to kg/ha at 14% moisture. Growth reductions in rice due to weed competition were calculated as follows: (parameter with 2 weedings - parameter with no weeding) / (parameter with 2 weedings) x 100/1.

## RESULTS AND DISCUSSION

The dominant weed species in both years was *Rottboellia cochinchinensis* (Lour.) W.D. Clayton. Other species present were *Echinochloa colona* (L.) Link, *Cyperus rotundus* L., *Cyperus compressus* L., *Digitaria* spp. , *Cyperus iria* L., *Eleusine indica* (L.) Gaertn., and *Dactyloctenium aegyptium* (L.) Beauv.

In 1995, total weed weight in unweeded plots was generally lower in Aus 257 than for other cultivars, although significance of effects varied with time (Fig. 1). In 1996, weed weights were not significantly different between cultivars regardless of sampling time. The difference in suppressive ability between years may have been due to less weed growth in 1996 than in 1995 (Fig. 1). Plant number were initially more in 1995 than in 1996 but tiller number were not very different between 1995 and 1996 at 8 WAE. Weed suppression by Aus 257 was observed also in studies conducted in Leyte in 1993 and 1994 (6).

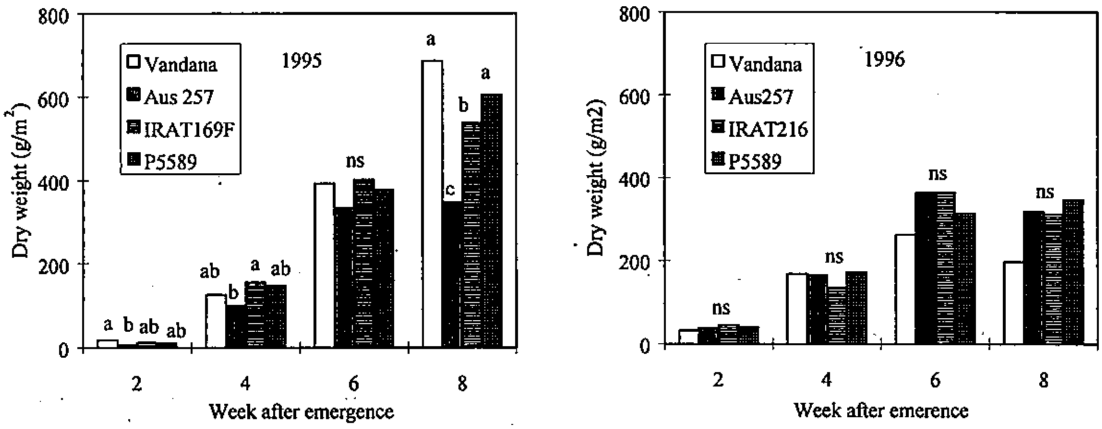


Figure 1. Dry weed weight (g/m2) under different rice cultivars in the unweeded plots at different growth stages. Bars within times with the same letter are not significantly different at 5% level by DMRT. ns - not significant.

Competitive cultivars generally had lower reductions in tiller number, height , leaf area index and dry weight due to weed competition than the noncompetitive cultivars (Fig. 2). For all cultivars, reductions in leaf area index and dry weight were greater than reductions in tiller number and plant height, leaf area index and dry weight being more sensitive to weed competition than tiller number and plant height. Fischer *et al.* (2) also found that plant height and tillering were least affected by competition. In 1995, leaf area index and dry weight were the rice traits which were most closely related to competitiveness (Table 1). In 1996, LAI and dry weight at 2 WAE were closely related to competitiveness but those in the later growth stages were not (Table 1). The variation may be due to differences in weed pressure between years; plots in 1996 had lower weed growth than in 1995 (Fig. 1).

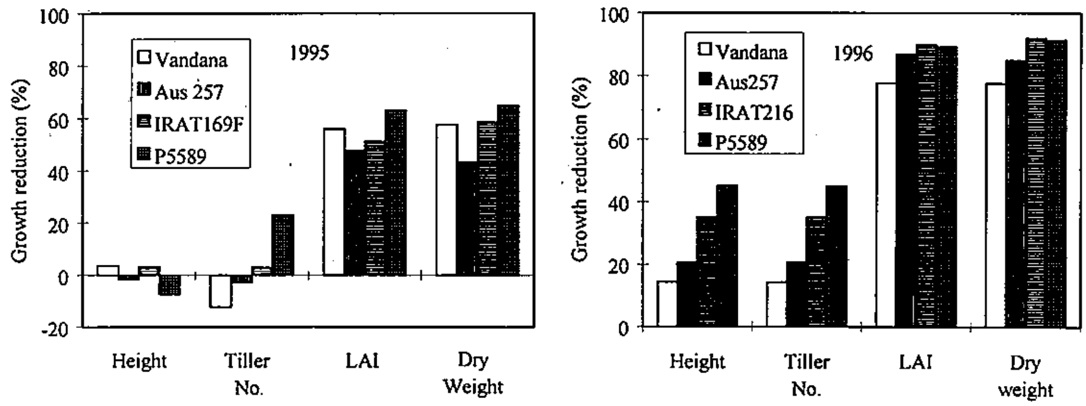


Figure 2. Reduction in growth of rice cultivars due to weed competition at eight weeks after emergence. LAI = leaf area index.

Table 1. Correlations between percentage rice yield reduction and above-ground rice characters from the unweeded plots at different stages of growth.

| Variables | | Week after emergence[1] | | | |
|---|---|---|---|---|---|
| X | Y | 2 | 4 | 6 | 8 |
| | | 1995 | | | |
| Height | Yield reduction | -0.225 ns | -0.020 ns | -0.381 ns | -0.365 ns |
| Tillers | Yield reduction | -0.250 ns | -0.490 ns | -0.152 ns | -0.319 ns |
| LAI | Yield reduction | -0.605 * | -0.718 ** | -0.747 ** | -0.694 ** |
| Dry weight | Yield reduction | -0.530 * | -0.605 * | -0.686 ** | -0.787 ** |
| | | 1996 | | | |
| Height | Yield reduction | -0.370 ns | -0.591 * | -0.564 * | -0.398 ns |
| Tillers | Yield reduction | -0.648 ** | -0.211 ns | -0.199 ns | -0.395 ns |
| LAI | Yield reduction | -0.709 ** | -0.476 ns | -0.387 ns | -0.175 ns |
| Dry weight | Yield reduction | -0.707 ** | -0.436 ns | -0.294 ns | -0.242 ns |

[1]ns - not significant, * -significant at 5% level, ** significant at 1% level

Yields were low (<500 kg/ha) and did not differ between cultivars in unweeded plots in both years (Fig. 3). However, competitive cultivars generally yielded higher (2-3 t/ha) than noncompetitive cultivars (<2 t/ha) when plots were weeded. In 1995, when plots were weeded, Vandana, Aus 257 and IRAT169F 10/6 had similar yields which were higher than that of P5589-1-1-3P. In 1996, Vandana and Aus 257 had higher yields than P5589-1-1-3P in the inter-row cultivated plots and than both IRAT216 and P5589-1-1-3P in the hand weeded plots. In 1995 and 1996, weed removal by hand increased yield of all cultivars. Inter-row cultivation did not increase rice yield in 1996 due to poor weed control.

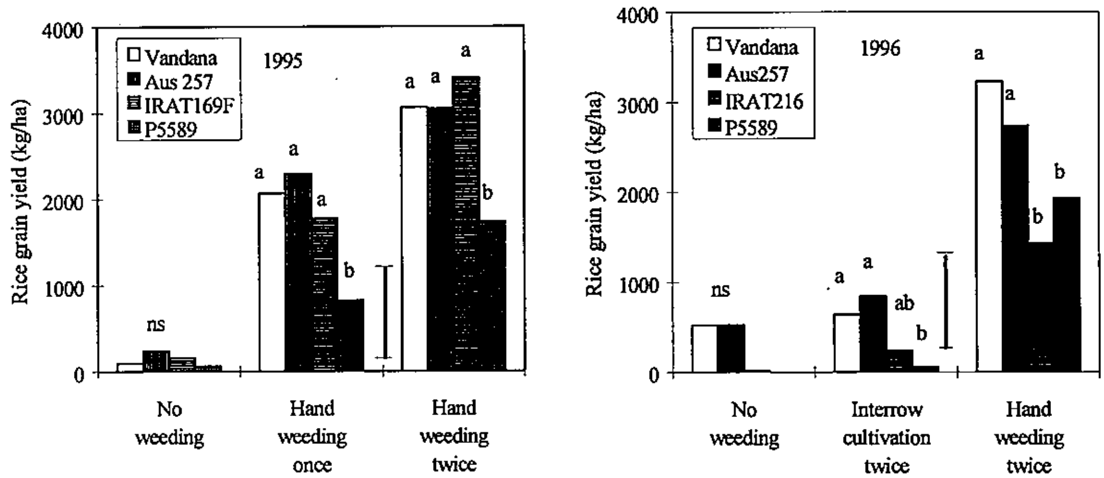


Figure 3. Yield of rice cultivars in response to weeding levels. LSD (0.05) bar to compare yields of the same cultivar across weeding levels. Bars within times with the same letter are not significantly different at 5% level by DMRT. ns - not significant.

The growth of weak competitors declines drastically compared to strong competitors under weed pressure (7). Reported advantages of competitive cultivars are they are capable of suppressing weed growth (6) and they reduce time spent for weeding (11, 12). Increases in yield in competitive cultivars can be attained with just one hand weeding while with non-competitive cultivars more than one hand weeding is generally needed to attain acceptable yield.

Competitive cultivars gave a relatively high yield with low or medium weed pressure but yielded poorly when not weeded. It is possible that more plant energy is spent in the production of vegetative attributes to survive and less for reproductive attributes in very weedy situations. This is possibly the reason why several workers (7, 10, 11) concluded that competitive ability is negatively correlated with yield.

In field situations, where the yield potential of two cultivars is the same, there may be advantages in terms of less effort to control weeds, better weed suppression, and higher yields, in using rice cultivars which are competitive with weeds. This study suggested that leaf area and dry weight are important traits in cultivar competitiveness. However, there was no evidence from this study that competitive cultivars or inter-row cultivation can substitute for hand weeding. "Competitive" cultivars still needed good weed control (two hand weedings) for optimum yield, with yield increasing by 1 t/ha or more with each increase in weeding level. Inter-row cultivation was little better than no weeding and could not replace hand weeding (or herbicides), because weeds remaining within the rice rows were highly competitive. ARS (1) reported that different inter-row cultivation implements reduced weed weight by only 20-50% because they failed to control weeds within the row. Crop losses of 30-50% occurred in these plots compared to 10% yield loss when herbicides (propanil + MCPA) were used for weed control.

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# EFFECTS OF WRINKLEGRASS DENSITY AND DURATION OF INTERFERENCE ON TRANSPLANTED RICE

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*Summary*: A series of pot experiments were conducted in an insect-proof house at the Institute of Advanced Studies, University of Malaya, Kuala Lumpur in 1995-1996 to evaluate the effects of wrinklegrass *(Ischaemum rugosum* Salisb.) density and duration of interference on yield and yield components of rice *(Oryza sativa* L var. MR 84). Rice seedlings were transplanted in pots at a constant density of 6 plants/pot together with wrinklegrass with variable densities of 14, 28, 42, 56, 70 and 84 plants/m$^2$. The duration of wrinklegrass interference on the rice crop for each density regime was 0, 2, 4, 6, 8, 10, and 21weeks. Wrinklegrass infestation at all density had a significant effect on rice yields and yield components. Wrinklegrass density had a more profound effect *vis-a-vis* than duration of interference especially in the first two weeks after transplanting. reduced total rice grain yield/plant, 17, 33, 34, 45 and 57% for weed density of 14, 28, 42, 56, 70 and 84 plants/m$^2$, respectively. The critical period of wrinklegrass control was between 4 and 7 weeks after transplanting for low and medium density (14, 42 plants/m$^2$, respectively) and between 2 and 6 weeks after transplanting for high density (84 plants/m$^2$).

*Keywords*: *Oryza sativa*, *Ischaemum rugosum*, critical period of interference

## INTRODUCTION

Competition between weeds and crops is a negative interaction that minimizes crop yields. Numerous studies have indicated that the yield loss in a two species mixture is inversely proportional to weed density (2, 7, 3). Crop losses inflicted by weeds also vary with the duration of weed infestation of the crops (3). Unless kept free from weeds during a part of its growing period (8), the crop is likely to experience yield reduction. This-weed free period is referred to as the critical period of weed control which in essence is the numerical time interval (5, 6, 12, 15, 16 17) between the maximum weed infested period after which the crop must be kept free from weeds emerging with crop and the minimum weed-free period until which the crop must be kept free from weeds following crop transplanting or seeding to avoid crop loss from weeds emerging thereafter (6, 14).

The negative influence and correlation between increased density and seeding rates on yield components are well documented (4, 9, 11) and such relationships are usually expressed as percentage of weight of grains/plant, number of filled grains, number of grains/panicle and number of panicles/plant. The objectives of this study were to evaluate the effects of wrinklegrass *(Ischaemum rugosum* Salisb.) density and duration of infestation and their relationships to the growth, yield and yield components of rice and to determine the critical period for wrinklegrass control in ricefields of Malaysia.

## MATERIALS AND METHODS

Wrinklegrass seeds collected from the Seberang Prai granary and a commercial rice variety MR84 from MARDI, Seberang Prai Research Station were pre-germinated in 9 cm diameter petri-dishes. Rice and wrinklegrass seedlings were sown in PVC pots filled with padi soils of the Java series. Rice seedlings were transplanted at a fixed density of six plants/pot (84/m$^2$). Wrinklegrass was then transplanted such that each pot-set was assigned to one of the six densities used in this study, *viz*: 14, 28, 42, 56, 70 or 84 plants/m$^2$. The pots assigned to each density regime were further subdivided into six sets with three replicates each. One set of each density was subjected to one of the six weed infestation periods, *viz*: 2, 4, 6, 8, 10 and 12 weeks. The same number of sets were assigned to one of six weed-free periods vis. 2, 4, 6, 8, 10 and 12 weeks. Another set of three pots was transplanted with 6 rice plants/pot and used as a control i.e. weed-free throughout the growing season. At the end of the 2, 4, 6, 8, 10 and 12 weeks after transplanting, wrinklegrass plants were removed from the respective pots. A set of 3 pots for each density was left unweeded until harvest. Rice was harvested upon ripening (108 after germination initiation). The data pertaining to yield components and critical period of wrinklegrass control were recorded. The growth data were subjected to two-way ANOVA and the subsequently fitted to the most appropriate growth curve model. Data pertaining to yield and its components were suitably best fitted to the general linear model (GLM) but critical period of wrinklegrass control as best fitted to polynomial model. Correlation between various yield components were made in order to evaluate the effects of wrinklegrass on rice yield and yield components. The critical period of wrinklegrass competition with the rice crop was determined using the method of Singh *et al.* (14) They defined this period as the time interval confounded between the point where the line established at a specified yield loss (depending on the cost of control) intersects the weed - infested regression line and the point where the regression yield on weed-free time and the yield on weed infested duration are equal. This in turn helps to determine the critical period of control of the weed. In this study the estimation of the critical period was based on a yield loss of 10% of weed-free rice yield.

## RESULTS AND DISCUSSION

Both Wrinklegrass density and duration of competition had significant negative influence on mean (average weight of 18 rice plants) total grain yield of rice (Fig 1), however, the effect of density was greater than competition duration on rice grain yields. The mean total grain yields/plant of rice decreased from *ca.* 6.50 g at a density of 14 wrinklegrass plants/m$^2$ to 4.00 g. at a density of 84 plants/m$^2$ (Fig. 1a). Wrinklegrass at such densities inflicted a respective loss of *ca.* 17 and 57% of rice yields *viz-a-viz* the weed-free controls. Neither wrinklegrass density nor duration of competition had a significant effect ($P<0.05$) on panicle length, number of empty grains/panicle, number of empty and filled grains/panicle and rice height, probably because these traits are genetically fixed for this rice variety.

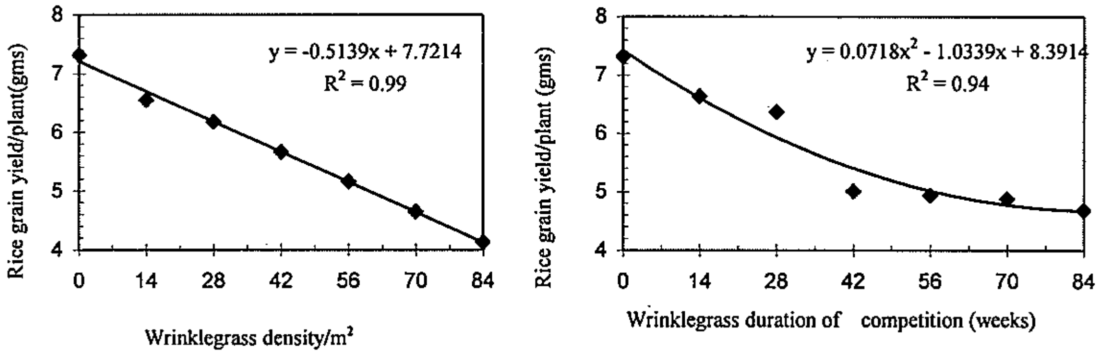


Figure 1. The effect of wrinklegrass density on the mean total grain yields of rice (over all durations) (a; fitted to linear model) and duration of competition (over all densities) (b; fitted to polynomial model).

The mean number of rice tillers/plant decreased significantly ($P<0.05$) as wrinklegrass density increased and they were reduced (Fig. 2) from about *ca.* 12 tillers/plant at wrinklegrass density of 14 plants/m$^2$ to 3 tillers/plant at a density of 84 plants/m$^2$ brought about a parallel decrease in rice grain yields. Arguably, wrinklegrass reduced growth and the yielding capacity of rice plants as a result of competition for nutrients, water and light. Competition from wrinklegrass led to significant reductions in the number of rice tillers which were found to be strongly correlated with the mean total yields of rice ($R^2 = 0.95$).

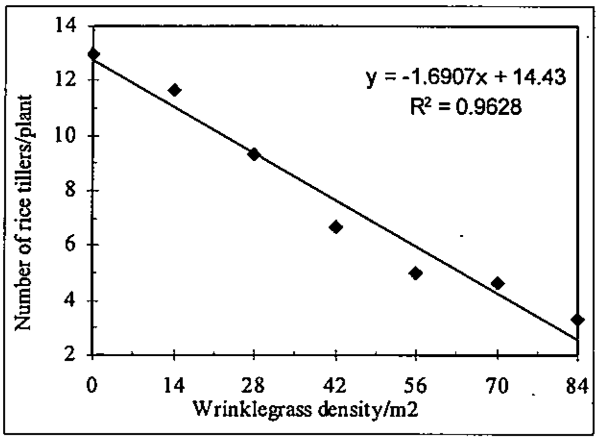


Figure 2. The infliction in the number rice tillers/plant as a result of increasing wrinklegrass density. (The broken line represents fitting to the linear model).

This reduction of tillers was probably enhanced by higher stature of wrinklegrass plants (*ca.* 130 cm in height) which resulted in shading of rice plants (*ca,* 90cm in height) and by the preponderance of wrinklegrass tillers (23 tillers/plant)(Table 1) which exhibited consistency in numbers even at high densities (84 plants/m$^2$).

Table 1. Effects of wrinklegrass density on rice grain yield and the number of tillers (/plant) and the heights of rice and wrinklegrass stems.

| Wrinklegrass Density/m$^2$ | % loss in rice grain yield/plant | Number of wrinklegrass tillers/plant | Plant height (cm) | |
|---|---|---|---|---|
| | | | Rice | Wrinklegrass |
| 14 | 17.83 | 23 | 95 | 120 |
| 28 | 33.3 | 24 | 92 | 128 |
| 42 | 33.47 | 26 | 87 | 130 |
| 56 | 33.65 | 22 | 91 | 135 |
| 70 | 44.99 | 22 | 94 | 136 |
| 84 | 57.06 | 24 | 90 | 122 |

In the first four weeks after transplanting, no meaningful competition was encountered by rice plants from the presence of wrinklegrass at low and medium densities (14 and 42 plants/m$^2$) thereby resulting in no significant effect on rice yields. Parallel studies by Lubigan and Moody (7) on competition between transplanted rice *var.* IR58 and wrinklegrass concluded that under wet condition at least 5 wrinklegrass plants reduced number of rice tillers and as a result wrinklegrass increased in density. The damage inflicted by wrinklegrass competition on rice yields and yield components was comparable to the damage caused by barnyardgrass. Andrade, (1) who reported that barnyardgrass at a densities of 4 and 100 plant/m$^2$ resulted in the loss of 16% and 89% in grain yields, respectively.

The mean total rice grain yields increased as the weed-free period increased (Fig. 3a and b). In contrast, rice yields decreased as the wrinklegrass infestation increased. The critical period for wrinklegrass control for low and medium wrinklegrass densities (14 and 42 plant/m$^2$) has been found to be between 4 and 7 weeks after transplanting. The critical period for wrinklegrass control at high density (84 plants/m$^2$) was estimated to be confounded between 2 and 6 weeks after transplanting. This narrow critical period at high density could be attributed to the earlier exertion of wrinklegrass influence on rice growth which in turn inflicted greater loss in rice yields. Wrinklegrass inflicts severe loss in rice yields if allowed to grow with rice for more than four weeks after transplanting. At higher density, however, control measures must be taken at between 2 and 6 weeks after transplanting in order to avoid a significant infliction in rice yield.

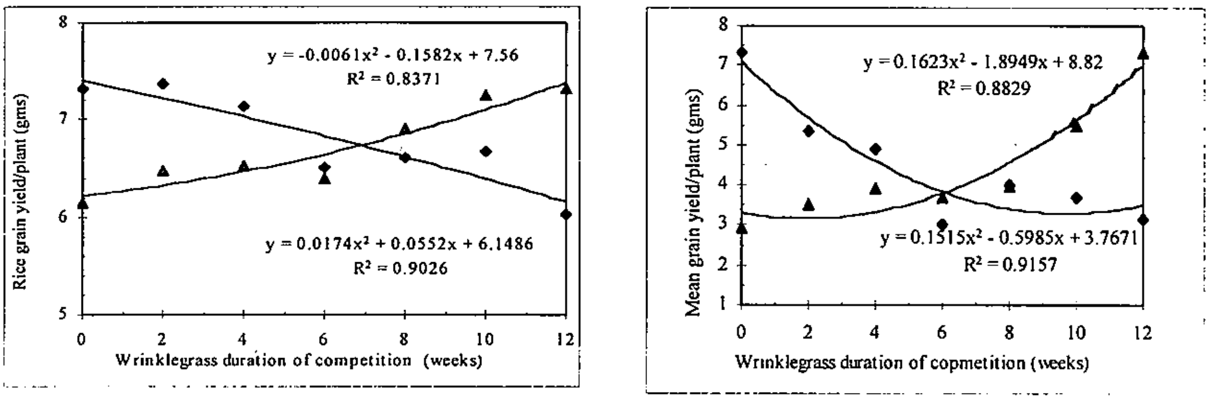


Figure 3. The critical period for wrinklegrass competition at low (a) and high (b). The data were fitted to polynomial model.(♦; represents rice yield as weed duration of competition increases and Δ; represents rice yield as weed free period increases).

## ACKNOWLEDGEMENTS

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# RICEGUARD 26WP: A NEW ONE SHOT HERBICIDE AGAINST VARIOUS WEEDS IN PADDY RICE IN CHINA AND IN THE PHILIPPINES

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*Summary:* Field trials were conducted in South and Central China and in the Philippines to evaluate the efficacy of RICEGUARD, a ready mixture of 250 g/kg anilofos and 10 g/kg ethoxysulfuron, against various weeds in paddy rice during 1993-1995. In China, RICEGUARD 26WP was applied at 150+6, 250+10, and 350+14 g ai/ha at 7 to 10 days after transplanting in early transplanted rice (ETR). In late transplanted rice (LTR), it was applied at150+6, 187+8, and 225+9 g ai/ha at 3 to 5 days after transplanting. RICEGUARD 26WP gave excellent control of annual grasses as well as annual and perennial sedges and broad-leaved weeds with good crop safety, when applied at 250+10 g ai/ha in ETR and 187+8 in LTR in South China, and at 250+10 g ai/ha in ETR and 225+9 in LTR in Central China, before the 2-leaf stage of annual grasses. In the Philippines, RICEGUARD 26WP applied at 250+10 g ai/ha at 5 to 7 days after seeding/transplanting provided excellent control of various annual weeds with good crop safety in lowland transplanted rice and wet-sown direct-seeded rice. The trial results confirmed the efficacy of RICEGUARD 26WP as an early post-emergence one shot herbicide in transplanted rice in South and Central China and in lowland, transplanted and wet-sown, direct-seeded rice in the Philippines.

*Keywords*: RICEGUARD, anilofos, ethoxysulfuron, rice weed control

## INTRODUCTION

RICEGUARD 26WP, a new one shot herbicide from AgrEvo, is a ready mixture of 250 g/kg anilofos and 10 g/kg ethoxysulfuron. Anilofos from AgrEvo is an effective herbicide against annual grasses and sedges in paddy rice (3). Ethoxysulfuron from AgrEvo is an effective herbicide against annual and perennial broad-leaved weeds and sedges in paddy rice (1, 2, 4, 5). RICEGUARD 26WP has high efficacy against various weeds in paddy field. This paper presents the summary of a series of field trials of RICEGUARD 26WP against various weeds in transplanted rice in South and Central China and in lowland transplanted as well as wet-sown direct-seeded rice in the Philippines.

## MATERIALS AND METHODS

*China*: More than 10 field trials were conducted in Central and South China in early and late transplanted rice during 1993-1995. Rice, at the 4 to 5-leaf stage, was transplanted in paddy fields. In ETR, Riceguard 26WP was applied with a dose rate of 150+6, 250+10, and 350+14 g ai/ha at 8 days after transplanting and at the 2-leaf stage of barnyardgrass. As commercial standard, DAOCAOWEI 14WP containing 120 g/kg acetochlor and 20 g/kg bensulfuron was applied at a rate of 72+12 g ai/ha at 8 days after transplanting. In LTR, RICEGUARD 26WP was applied at 150+6, 187+8, and 225+9 g ai/ha at 4 to 5 days after transplanting before the 1-leaf stage of barnyardgrass. In both cases, RICEGUARD 26WP was applied by mixing the desired dosage with 150-300 kg/ha sandy paddy soil. All treatments in each trial were replicated 4 times in a randomized complete block design. The plot size for each replicate was ranged from 15 to 20 $m^2$. Weed control was assessed at 20, 35 or 40 days after applications in ETR and at 40, 45 or 50 days after application in LTR by recording weed counts and weed biomass. The measurement of rice yield was obtained by harvesting the whole plot.

*Philippines*: More than 40 field trials have been conducted since 1993 at the AgrEvo Research Station in the Philippines as well as in actual farmer's field to assess the performance of AROZIN 30EC (anilofos), SUNRICE 15WDG (Ethoxysulfuron) and Riceguard 26WP against common annual weeds in paddy rice. In all of the field trials, the compounds were tested in both wet-sown direct-seeded and lowland transplanted rice using IR36 and IR64 varieties in plot sizes ranging from 4 to 100 $m^2$. Application was made using either a $CO_2$ driven boom sprayer fitted with flat fan nozzles or a knapsack (Mesto brand) pressurized sprayer equipped with a hollow cone nozzle delivering a spray volume of 200 L/ha. Parameters evaluated included biological efficacy (by visual assessment, weed count and weed biomass) against various annual weeds, crop safety and timing of application.

## RESULTS AND DISCUSSION

*Weed Control China*: In ETR, RICEGUARD 26WP gave excellent control of various weeds including annual grasses as well as annual and perennial broad-leaved weeds and sedges (Table 1). For obtaining these results in South China, 150+6 g ai/ha were required while in Central China, RICEGUARD 26WP applied at 250+10 g ai/ha provided best efficacy. No significant differences were observed compared to the commercial standard. In LTR RICEGUARD 26WP gave similar performance as in ETR (Table 2). In South China, a rate of 187+8 g ai/ha provided more than 98% control of annual grasses and perennial broad-leaved weeds and sedges. In Central China, RICEGUARD 26WP applied at 225+9 g ai/ha offered better total control than the commercial standard. These results confirmed RICEGUARD 26WP as a very effective compound to be used as an early post-emergence, one shot herbicide in transplanted rice in China.

*Philippines*: AROZIN 30EC applied at 250 to 300 g a.i./ha provided outstanding control of annual grasses and sedges at 1 to 7 days after seeding/transplanting. At that time, the target grass weeds had not reached the 2-leaf stage of development. As expected, it was not effective against broadleaf weeds (Table 3). SUNRICE 15WDG, on the other hand, provided excellent control of annual sedges and broad-leaved weeds at 2 days before seeding/transplanting to 9 days after seeding/transplanting. As expected, the compound showed no efficacy against grasses (Table 3). RICEGUARD 26WP at (250+10) g ai/ha, provided excellent control of the entire weed spectrum in rice. Best results with respect to efficacy were obtained when the application of RICEGUARD 26WP was made at 3 to 7 days after seeding/transplanting (Table 3).

*Crop Safety, China*: RICEGUARD 26 WP showed very good selectivity to rice crop, similar to the commercial standard used, when applied as an early post-emergence herbicide in both early and late transplanted rice, in South and Central China. No significant differences in yield were observed between herbicide treatments. (Table 1 and 2).

*Philippines*: In lowland, transplanted rice using "dapog" seedlings, AROZIN 30EC, SUNRICE 15WDG and RICEGUARD 26WP caused no injurious effect on the crop at all test periods of application (Table 4). In wet-sown, direct-seeded rice, however, the window of application appeared to be narrower. Because of the mode of action of anilofos, it has to be applied at 5 to 7 days after transplanting. Symptoms of injury occurred when applied earlier and were characterized mainly by stunted growth often times accompanied by leaf twisting and excessive greening. It is worthy to note, however, that the crop distinctly develops resistance to AROZIN 30EC as it grows older as evidenced by the almost negligible damage caused by AROZIN 30EC and RICEGUARD 26WP when applied at 5 days after seeding onwards and the non-occurrence of any phytotoxicity symptoms when applied at 7 days after seeding. Rice plants sprayed at 5 days after seeding sustained negligible crop damage and quickly recovered from injury within 3 to 7 days after application.

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Table 1. Average efficacy of RICEGUARD 26WP against various weeds in early transplanted rice – China

| Region | Herbicide | Dosage (g ai/ha) | Efficacy(%) | | | | Yield (Kg/ha) |
|---|---|---|---|---|---|---|---|
| | | | Annual grasses | Annual BLW/sedges | Perennial BLW/sedges | Average | |
| South China | RICEGUARD 26WP | 150+6 | 97.9 | 98.0 | 85.0 | 93.6 | 6029.0 |
| | RICEGUARD 26WP | 250+10 | 98.5 | 97.7 | 100.0 | 98.7 | 5936.0 |
| | RICEGUARD 26WP | 350+14 | 97.9 | 100.0 | 100.0 | 99.3 | 5512.5 |
| | DAOCAOWEI 14WP | 72+12 | 97.2 | 90.0 | 60.0 | 82.4 | 6022.0 |
| | CK (No weeding) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4050.0 |
| Central China | RICEGUARD 26WP | 150+6 | 79.0 | 97.5 | 98.0 | 99.0 | 5101.0 |
| | RICEGUARD 26WP | 250+10 | 100.0 | 100.0 | 100.0 | 100.0 | 5313.0 |
| | RICEGUARD 26WP | 350+14 | 100.0 | 100.0 | 100.0 | 100.0 | 5346.0 |
| | DAOCAOWEI 14WP | 72+12 | 100.0 | 100.0 | 100.0 | 100.0 | 5211.0 |
| | CK (No weeding) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4672.0 |

Annual grasses: *Echinochloa crus-galli*
Annual BLW/sedges: *Cyperus difformis, Marsilea quadrifolia, Monochoria vaginalis*
Perennial BLW/sedge: *Sagittaria pygmaea, Eleocharis yokoscensis, Scirpus juncoides*

Table 2. Average efficacy of RICEGUARD 26WP against various weeds in late transplanted rice - China

| Region | Herbicide | Dosage (g ai/ha) | Efficacy(%) | | | | Yield (Kg/ha) |
|---|---|---|---|---|---|---|---|
| | | | Annual grasses | Annual BLW/sedges | Perennial BLW/sedges | Average | |
| South China | RICEGUARD 26WP | 150+6 | 96.0 | 92.6 | 75.0 | 87.9 | 6426.6 |
| | RICEGUARD 26WP | 187+8 | 98.7 | 99.7 | 100.0 | 99.5 | 6500.8 |
| | RICEGUARD 26WP | 225+9 | 98.7 | 99.7 | 100.0 | 99.5 | 6221.2 |
| | DAOCAOWEI 14WP | 72+12 | 94.8 | 97.4 | 100.0 | 97.4 | 6375.3 |
| | CK (No weeding) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5707.5 |
| Central China | RICEGUARD 26WP | 150+6 | 82.8 | 81.8 | 83.3 | 82.6 | 5700.0 |
| | RICEGUARD 26WP | 187+8 | 92.0 | 95.7 | 92.8 | 93.5 | 5899.5 |
| | RICEGUARD 26WP | 225+9 | 100.0 | 97.4 | 98.3 | 98.6 | 6000.0 |
| | DAOCAOWEI 14WP | 90+15 | 100.0 | 91.3 | 94.8 | 95.4 | 5850.0 |
| | CK (No weeding) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4924.5 |

Annual grasses: *Echinochloa crus-galli*
Annual BLW/sedges: *Rotala indica, Bidens tripartita, Ludwigia prostrata, Cyperus iria, Fimbristylis miliacea, Monochoria vaginalis*
Perennial BLW/sedge: *Sagittaria sagittifolia, Sagittaria pygmaea, Juncellus serotinum*

Table 3. Efficacy of AROZIN 30EC, SUNRICE 15WDG and RICEGUARD 26WP against various annual grasses, sedges and broadleaves in lowland paddy rice as affected by timing of application - Philippines

| Herbicides | Dosage range (g ai/ha) | Weed Group | Efficacy (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | -2 DAS/DAT | 1 DAS/DAT | 3 DAS/DAT | 5 DAS/DAT | 7 DAS/DAT | 9 DAS/DAT |
| AROZIN 30EC (Anilofos) | 250-300 | Grasses | 85 | 93 | 95 | 97 | 93 | 48 |
| | | Sedges | 62 | 71 | 97 | 100 | 97 | 45 |
| | | Broadleaves | 0 | 10 | 26 | 0 | 0 | 0 |
| SUNRICE 15 WDG (Ethoxysulfuron) | 7.5-10 | Grasses | 6 | 0 | 0 | 17 | 19 | 0 |
| | | Sedges | 100 | 100 | 100 | 100 | 100 | 100 |
| | | Broadleaves | 100 | 95 | 100 | 100 | 100 | 100 |
| RICEGUARD 26WP | 260 | Grasses | 98 | 88 | 100 | 98 | 95 | 43 |
| | | Sedges | 31 | 80 | 100 | 100 | 100 | 100 |
| | | Broadleaves | 38 | 70 | 99 | 100 | 100 | 100 |
| Mean Leaf Stage of weeds at Application Time | | Grasses | 0 LS | 0 LS | 1 LS | 1-2 LS | 1-3 LS | 2-4 LS |
| | | Sedges | 0 LS | 0 LS | 1-2 LS | 1-2 LS | 1-2 LS | 2-3 LS |
| | | Broadleaves | 0 LS | 0 LS | 2 LS | 2 LS | 2-4 LS | 2-4 LS |

DAS = days after seeding; DAT = days after transplanting; LS=leaf stage

Table 4. Maximum percent phytotoxicity of Arozin 30EC, Sunrice 15WDG and Riceguard 26WP in wet-sown, direct-seeded and lowland, transplanted rice cv. IR 64 as influenced by timing of application - Philippines

| Herbicides | Dosage Range (g ai/ha) | Rice Culture | Phytotoxicity (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | -2 DAS/DAT | 1 DAS/DAT | 3 DAS/DAT | 5 DAS/DAT | 7 DAS/DAT | 9 DAS/DAT |
| Anilofos 30EC (Anilofos) | 250-300 | LLTP | 0 | 0 | 0 | 0 | 0 | 0 |
| | | WSDS | 0 | 65 | 72 | 12 | 0 | 0 |
| Sunrice 15 WDG (Ethoxysulfuron) | 7.5-10 | LLTP | 0 | 0 | 0 | 0 | 0 | 0 |
| | | WSDS | 0 | 0 | 0 | 0 | 0 | 0 |
| Riceguard 26WP | 260 | LLTP | 0 | 0 | 0 | 0 | 0 | 0 |
| | | WSDS | 0 | 62 | 74 | 8 | 0 | 0 |

WSDS=wet-sown, direct-seeded; LLTP=lowland, transplanted

# WEED MANAGEMENT IN INDONESIAN TIDAL SWAMP RICE PRODUCTION

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*Summary*: Tidal swamp areas in Indonesia were considered to have high potential to be developed for rice production since the environmental, technological and socio-economic conditions were conductive to support its implementation. Technological requirement for rice production in tidal swamp areas should be based on specific locations due to the highly variable characteristics of tidal swamp areas compared to the normal innundated rice areas, especially in Java. One of the major problems of rice in tidal swamp areas is weeds. Weeds interfere with land preparation and compete with rice crops resulting in low yields of rice. Weed control techniques to be adopted should not only have ability to control weeds during rice growth and development, but also facilitate easy land preparation. Experiences with use of herbicides such as paraquat, sulphosate and glyphosate, that proved to be successful for rice culture in some tidal swamp areas in Kalimantan are discussed.

*Keywords*: tidal swamp rice, minimum tillage, zero-tillage

## INTRODUCTION

Swamp land is becoming more important as a new frontier for agricultural development after priority has been given to the irrigated lowland and dry land. It is estimated that 20.1 million ha out of 3.4 million ha of swamp are tidal swamps and another 13.3 million ha belong to fresh-water swamps. About nine million ha of swamp land, which spreads over the islands of Sumatera, Kalimantan, Sulawesi and Irian Jaya are considered suitable for agricultural production (1).

Swamp land is distinguished into three zones: salinistic tidal swamp, fresh water tidal swamp and non-tidal swamp areas. The influence of tide in the rainy season will describe the tidal swamp and non-tidal swamp zones (1). The tidal swamps are grouped into four typologies (2) *viz*, potential, acid sulphate peat and saline, with flooding types of A, B, C and D; while the fresh water swamps are classified into shallow, medium (moderate) and deep swamps The potential land consists of a toxic pyritic layer at a depth of more than 50 cm from the soil surface; hence cultivating these lands entails some risks.

There are many constraints and risks in the management of rice production in tidal swamp areas. Physical factor constraints may involve water tide, acidity, toxic solutions, low soil fertility and poor physical soil conditions. Biological constraints consists of lack of suitable rice varieties and attack by pest organisms, while socio-economic constraints are low level of education, traditional cultural characteristics, low labour, lack of capital and limited farm size. One of the major physical constraints is land preparation, which has specific implications in rice production. Complete tillage favoured iron toxicity effects or increased the acidity due to sulphates. Thus, minimum or no-tillage offers alternative approaches for land preparation. Also, manual weeding is time consuming and costly and herbicides are a suitable alternative for weed management in tidal swamp rice production areas. However proper selection of herbicides, doses and time of application is necessary to implement rice production in tidal swamp areas with no-tillage or minimum tillage techniques.

## NEED FOR ALTERNATIVE TECHNIQUES IN TIDAL SWAMP AREAS

Generally land preparation in tidal areas are somewhat different to those in irrigated rice fields. Farmers do not plough and harrow the land, but use traditional methods that consumes time. Weeds are simply slashed with a simple tool, andd allowed to decompose for a couple of weeks. The decomposed weeds are then collected into heaps. The turning over of heaps is necessary to favour the decomposition process. At planting time all the weeds are expected to be decomposed completely and distributed over the land area evenly. This traditional method takes about two months. Weeds are controlled manually and yields are low.This technique is considered weak, since it is time consuming and land preparation is generally poor. It is uneconomical, as 1.0 ha of tidal land requires 235.4 man-days of labour for land preparation.

## HERBICIDE TECHNOLOGY FOR TIDAL SWAMP RICE CULTIVATION

As efforts to manage weeds with conventional methods is considered ineffective and inefficient, alternatives to managing weeds is the use of proper herbicides for land preparation and maintenance of rice cultivation. Firstly, all weeds (vegetation) controlled by herbicides act as mulches over the surface of the area, and will be decomposed afterwards. Secondly, the herbicides should be safe to the rice plant and environment as well as non-target organisms. Thirdly, the technology should be acceptable to farmers, and must have economical advantages. Therefore, the suitability of the herbicide including the rate and methods of application is very important.This technology will not interrupt or cause major structural damage to tidal swamp areas, since no mechanical and physical activities are adopted. The natural vegetation in the areas is replaced by the mulch and the rice plants during the growing season.Suitable herbicides for tidal swamps are presented in Table 1. In the field studies, most of the dominant weed species in the area were controlled by application of glyphosate and paraquat based herbicides.

Table 1. Suitable herbicides, their rates and time of application in tidal swamp rice cultivation.

| Herbicides | Rate (L/ha) | time of application | area type |
|---|---|---|---|
| Land preparation | | | |
| 1. Paracol (paraquat+diuron) | 3.0 | 7-10 dbt | ABCD |
| 2. Gramoxone (paraquat) | 3.0 | 7-10 dbt | ABCD |
| 3. Roundup (glyphosate) | 3.0 | 21 dbt | CD |
| 4. Polaris (glyphosate) | 6.0 | 21dbt | CD |
| 5. Touchdown (sulfosate) | 1.5 | 21 dbt | CD |
| Crop maintenance | | | |
| 1. DMA 6 2,4-D | 0.75-1.0 | 7-14 bat | ABCD |
| 2. Agroxone 4 MCPA | 0.75-1.0 | 7-14 dat | ABCD |
| 3. Lindomin 2,4-D | 0.75-1.0 | 7-14 dat | ABCD |

dbt : days before transplanting
dat : days after transplanting
ABCD: types of tidal swamp areas

Weed species controlled were: *Axonoponus compressus, Digitaria adscendens, D. sanguinalis, D. ciliaris, Echinochloa colona, Elausine indica, Ischaemum timorense, Paspalum conjugatum* and other grass species; and broadleaf *species Ageratum conyzoides, A. houstonianum, Alternanthera braziliana, Amaranthus spinosus, Borreria alata, Cleome aspera, Drymaria cordata, Oldenlandia spp.* and others.

## PROSPECTS FOR ADOPTION IN TIDAL SWAMP AREAS

Farmers need to overcome weed problems in land preparation and crop maintenance using simple technologies, and herbicides that are available and easy to handle offer advantages to farmers.The use of herbicides for rice production in tidal swamp areas in Indonesia is estimated to be only 463-773 ton/year.The constraints to adoption of herbicides in the tidal swamp areas are low skills and education of farmers.The distribution of technical information to farmers in tidal swamp areas through extention and education is badly needed.

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FENOXAPROP-P-ETHYL IS AN EFFECTIVE HERBICIDE IN CONTROLLING RED SPRANGLETOP [*LEPTOCHLOA CHINENSIS* (L.) NEES]

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*Summary*: A greenhouse study on the effectiveness of fenoxaprop-P-ethyl in controlling red sprangletop [*Leptochloa chinensis* (L.) Nees] was conducted twice, the first trial was from November 1994 to January 1995, the second trial was from February to Aphi 1995. The results strongly indicated that propanil or thiobencarb alone and the mixtures were effective in controlling the red sprangletop, particularly when applied at earlypost-emergence stage. However, late application of the herbicides was not effective. Although significant injury was observed, the plants could recover and regrow. Among all tested herbicides, fenoxaprop-P-ethyl was the most effective in controlling red sprangletop, especially when sprayed at 10 and 18 days after seeding.

*Keywords: Leptochloa chinensis,* post-emergence, fenoxaprop-P-ethyl

## INTRODUCTION

In Malaysia, the recent rapid development in rice production technology is mainly due to the labour shortage. The introduction of direct-seeding methods for the establishment of the rice crop, has resulted in the wide use of machines for land preparation and harvesting and usage of herbicides for weed control. In direct-seeding fields, handweeding is more difficult, because farmers can no longer move freely between the rice plants. Hand-weeding can destroy rice plants, and in the early stages of growth, some grassy species are difficult to distinguish fiom rice seedlings. As hand-weeding is impractical in broadcast seeded ricefields, herbicide use is the obvious alternative for weed control (10, 16, 17).

To obtain suitable and effective herbicides for weed control in broadcast seeded rice is more difficult than in transplanted rice. In direct-seeding, the seeds of rice and weeds germinate at about the same time, and thus a more selective herbicide is required compared to transplanted rice (8).

The experience in herbicide usage in Malaysia is relatively similar to other countries. For example, in Muda area several post-emergence herbicides such as propanil, propanil+molinate, and fenoxaprop-P-ethyl are widely used by farmers, particularly to control grassy weeds. With the availabilty of water in the ricefields, farmers also use molinate, thiobencarb, and EPTC to control grass, particularly *Echinochloa* ssp. Some herbicides do not have broad weed control spectrum and certain weed species cannot be controlled effectively (14).

The main objective of this study is to determine the efficacy of several herbicides which are being widely used by farmers in direct-seeded ricefields in Malaysia, especially in Muda area, for controlling *L. chinensis.*

## MATERIALS AND METHODS

Two experiments were conducted in the greenhouse at the School of Biological Sciences, Universiti Sains Malaysia (USM), Penang. The first trial was conducted from November 1994 to January 1995 and the second from February 1995 to April 1995. Six post-emergence herbicides were applied in a variety of combinations and application times. There was one control treatment. Herbicide rates were based on the recommendation by Agricultural Chemicals (M) Penang (1). These treatments were tested by using a randomized block design and replicated three times. All treatments are shown in Table 1 and 2.

Each plastic tray was filled with 4.5 kg soil collected from Alor Serdang, Muda area (Kangkong Soil Series, 72% clay, 7% sand and 18% silt). Fertilizers were applied to each tray at the rate of 40 kg N/ha, 45 kg of $P_2O_5$/ha and 30 kg $K_2O$/ha as basal fertilization which were equal to 0.2 g of urea, 0.29 g of TSP (Triple Super Phosphate) and 0.19 g of KCl, respectively.

The seeds of red sprangletop were collected from Alor Serdang, Kedah, about two weeks before the trials. The seeds were soaked in water for 24 h and put in moist bags for another 48 h. Twenty-five pregerminated seeds were sown in each tray. The post-emergence herbicides were applied at 8 and 10 days after seeding (DAS), i.e. at 2 to 3 leaf stage and at 15 and 18 DAS, i.e. at 3 to 4 leaf stage. Herbicides were applied at 300 L/ha using a knapsack sprayer with T-jet nozzle.

Weed control was assessed usually as percentage control (100% = dead) at 15 and 30 DAS. Dry weights of red sprangletop were measured at 30 DAS. Percentages of plant population was computed from the equation, i.e.,

$$\text{Percentage of the plant population (\%)} = \frac{\text{Number of dead plants}}{\text{25 plants}} \times 100\%$$

Data analysis was based on the program of IRRISTAT and significant ddference was tested at the 5% level by Duncan Multiple Range Test (DMRT) (11, 12).

## RESULTS AND DISCUSSION

*Degree of weed control*: Propanil alone (Figure 1 & 2) gave better control of red sprangletop when applied at 8 DAS. Immediately after spraying propanil, a contact herbicide, caused leaf-burn and subsequently killed the plants. Late application at 15 DAS, was not effective and the plants recovered by 30 DAS. Therefore, application time of propanil was very important to obtain good control of red sprangletop. According to De Datta (9), propanil generally controlled annual grasses and a few broad-leaved weeds and sedges. However, complete coverage by spraying was essential to obtain good contact and effective weed control. Therefore, the field must be well drained in order to expose the leaves to the herbicide.

The propaniltmolinate mixture did not control red sprangletop although it was more effective in the second trial. Tank-mix of propanil/molinate is expected to have synergistic effect on this species. Ashton and Crafts (3) added that molinate was most useful as a pre-plant, soil-incorporated herbicide for use on water-seeded rice. Oeike and Morse (19) also reported that barnyardgrass was satisfactorily controlled by propanil applied at 3 to 4 tiller stage. However, rice yield was reduced significantly when rice was allowed to compete with the grassy weeds during this period.

In both trials, EPTC/2,4-D showed very poor control on red sprangletop. It was mentioned by De Datta (9) that 2,4-D was a post-emergence herbicide which was effective for control of sedges and broadleaf weeds, but annual grasses could be controlled when applied at pre-emergence. Ashton and Crafts (3) added that EPTC is a pre-emergence herbicide which is commonly incorporated mechanically to a depth of 2 to 3 inches. Therefore, results showed that the usage of EPTC and 2,4-D as a post-emergence herbicide would not be effective for control of grassy weeds such as red sprangletop.

When thiobencarb was applied as early post-emergence herbicide, R consistently gave adequate control of red sprangletop. Apparently, with late application at 15 DAS, gave very poor weed control. Therefore, to kill this species the herbicide must be applied at about 2 to 3 leaf stage. At early post-emergence, thiobencarb caused stunted growth with curly leaves on the red sprangletop. Abnormal growth indicates early inhibition in the development of leaf meristem. Therefore, several days after the application, the field should be flooded to kill the small seedlings thoroughly.

In both trials, thiobencarb/propanil mixture controlled red sprangletop when applied at 8 DAS. Seemingly, this result was similar to those when the species was applied with propanil and thiobencarb alone at 8 DAS (Table 1 and 2). Most plant leaves were burnt and chlorotic leaf occurred when completely covered with propanil. However, the weeds were able to recover and produced new shoots.

In the first trial, the plants were killed by fenoxaprop-P-ethy There was 1% plant population remaining when treated with the herbicide (Table 1). In the second trial, fenoxaprop-P-ethyl was also superior among all herbicides tested for controlling the species (Table 2). According to Katanyuku and Wirojchewan (15), Azmi and Lo (4), and Azmi and Supaad (5), fenoxaprop-ethyl mixture applied 16 DAS still gave serious crop injury. However, the crop injury disappeared 2-3 weeks after herbicide application and, vegetative growth of rice was not adversely affected by the herbicide.

*Growth and dry weight of red sprangletop*: Numbers of live plants also reflect the number of plants killed by the herbicides (Table 1 and 2). EPTC/2,4-D did not reduce the population of red sprangletop. The same result was obtained when propanil, thiobencarb and propanilmolinate were applied at 15 to 18 DAS. Red sprangletop was moderately controlled by applications of propanil and thiobencarb/propanil at 8 DAS. However, best result was obtained when fenoxaprop-P-ethyl was applied at 10 and 18 DAS, when the red sprangletop was controlled effectively.

The occurrence of foliar-burn and chlorotic leaves by propanil was considered inconsequential because the plant recovered within 14 days after application. De Datta (9) stated that propanil applied at 3.3-5.5 kg/ha could control *E. crus-gaili* 2.5-7.5 cm tall (1-4 leaf stage) with little or no injury to rice, but propanil was ineffective as a pre-emergence herbicide or when applied to *E. crus-gaili* at tilledng stage or later. But for bearded sprangle-top, Carrey *et al* (7) found that plants less than 1 cm tall are susceptible to propanil.

Oelke and Morse (19) and Smith (21) reported that a mixture of propanil and molinate each at 2.2 kg/ha, applied to weeds 8 to 10 cm tall (1-4 leaves) controlled tighthead sprangletop [*Leptochloa panicoides* (Presi) Hftchc] but propanil or molinate did not control bearded sprangletop [*Leptochloa fascicularis (Lam.)* Gray].

EPTC/2,4-D applied at early post-emergence and post-emergence did not control red sprangletop, therefore the highest total dry weight was produced. The dry weights of root and shoot were high which were comparable to that of an untreated plant (Table 1 and 2). Dry weights of root and shoot in treatments with thiobencarb 1.25 kg aiha at 8 DAS was still high, although the initial control was good. Red sprangletop was moderately damaged and the plant stunted with curly leaves, thereby, the dry weights of shoot decreased compared to that of an untreated plant. Mixture of EPTC and 2,4-D had no effect on red sprangletop when applied as early-emergence and post-emergence herbicides. Therefore, the usage of these herbicides continuously could encourage the buildup of resistant red sprangletop population.

Thiobencarb retarded the growth of new leaves and caused swelling of cells. The cells of the shoot apices of treated seedlings were often vacuolated. Thiobencarb inhibited the growth of germinating weeds. The usage of thioncarb alone or in combination with other herbicides, could effectively control barnyardgrass and red sprangletop and other weed species when applied with pre-emergence or early post-emergence herbicides (20).

Fenoxaprop-P-ethyl was satisfactory for control of red sprangletop when applied at both early post-emergence and post-emergence. The least dry weight of roots and shoots were obtained in these treatments (Table 1 and 2). However, phyototoxicity of the herbicide to rice plants at early application is an important aspect to be considered. Fenoxaprop-P-ethyl is a foliar herbicide, where it is absorbed and translocated to meristimatic region. Initially, treated plants exhibit chlorosis in developing leaves and a cessation of growth. Within a few days necrosis of the shoot apex and meristimatic regions of leaves and roots is apparent (13) and also inhibits fatty acid synthesis (6). Therefore, fenoxaprop-P-ethyl caused high injury to some cereal crops, unless applied with a safener, fenchforazole-ethyl [ethyi-l-(2.4-dichlorophenyi)-5-thchforomethyi-1H-1,2,4triazol-3- carbomate] (23).

The differential effects of herbicides on weeds depend on several factors such as uptake, retention, and transiocation which in turn could be influenced by such structural features of the plant as leaf architecture, hairness, and thickness of cuticle, age of the plant and a wide range of physiological and biochemical phenomena (3, 22). When a herbicide is continuously used, there is always the danger of buildup of weed populations that are difficult to control (2, 18). Therefore, the rotation of several herbicides is very important to prevent the development of new resistant weed species. In the Muda ricefields, when molinate, 2,4-D and EPTC were applied continuously or when propanil and thiobencarb were always sprayed as post-emergence herbicides, the population of red sprangletop was not affected. Hence, the species has become one of the noxious grassy weeds in the area. Improper application time of a certain herbicide could also encourage buildup of the tolerant weed species.

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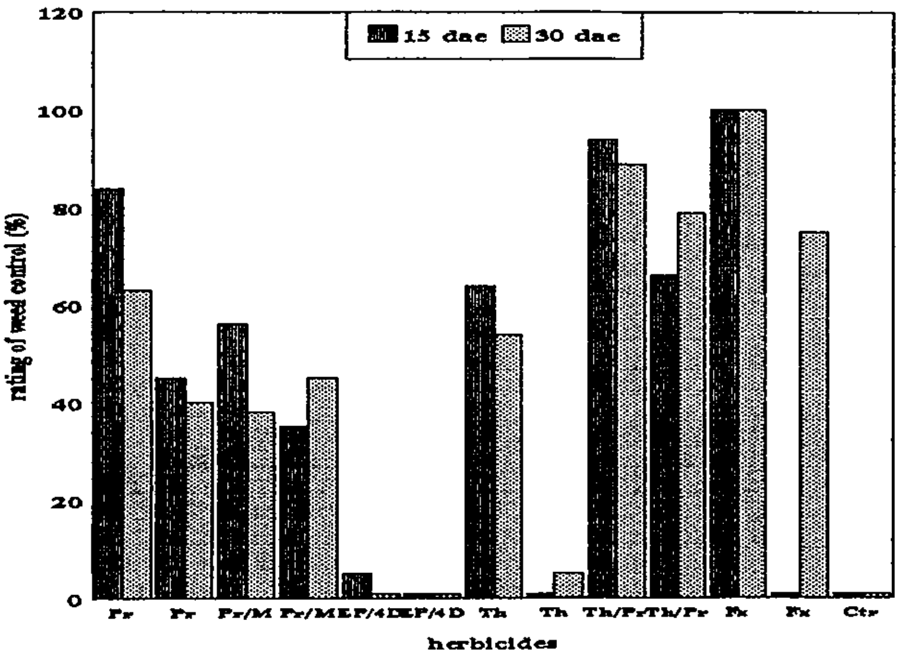


**Figure 1: Percentage of weed control of several postemergent herbicides on red sprangletop (first trial)**

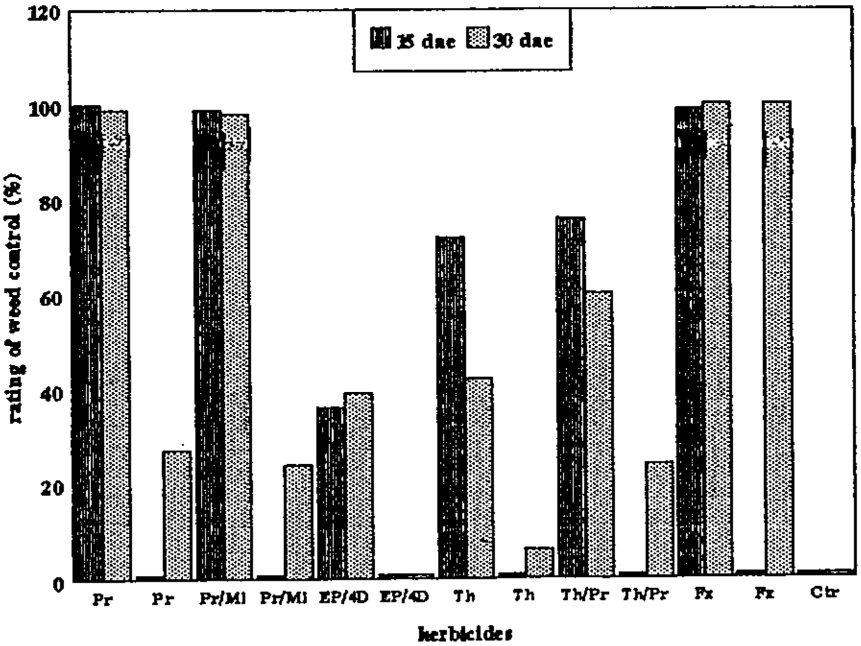


**Figure 2: Percentage of weed control of several postemergent herbicides on red sprangletop (second trial)**

Table 1. Plant population and dry weight of red sprangletop which were applied with several post-emergence herbicides at 30 DAS.

| Treatment | Percentage of plant population | Dry weight of red sprangletop | | |
|---|---|---|---|---|
| | | root | shoot | total |
| Propanil 2.0 kg ai/ha, 8 DAS | 70c | 1.3 abc | 2.3 bc | 3.6 bcd |
| Propanil 2.7 kg ai/ha, 15 DAS | 100 d | 2.8 cde | 4.7 d | 7.5 de |
| Propanil/molinate 1.5/1.5 kg ai/ha, 8 DAS | 69 c | 2.5 bcd | 4.0 cd | 6.5 cde |
| Propanil/molinate 2.0/2.0 kg ai/ha, 15 DAS | 98 d | 2.4 bcd | 3.9 c | 6.3 cde |
| EPTC/2, 4 D butyl ester 1.0/0.4 kg ai/ha, 10 DAS | 100 d | 7.9 g | 8.7 e | 16.6 g |
| EPCT/2, 4 D butyl ester 1.2/0.5 kg ai/ha, 18 DAS | 100 d | 5.6 efg | 9.4 e | 15.0 fg |
| Thiobencarb 1.25 kg ai/ha, 8 DAS | 60 c | 4.5 def | 5.5 d | 10.0 ef |
| Thiobencarb 3.0 kg ai/ha, 15 DAS | 100 d | 7.2 fg | 8.9 e | 16.1 g |
| Thiobencarb/propanil 1.2/0.6 kg ai/ha, 8 DAS | 25 b | 0.8 ab | 1.3 ab | 2.1 ab |
| Thiobencarb/propanil 2.4/1.2 kg ai/ha, 15 DAS | 66 c | 1.2 abc | 2.0 bc | 3.2 bc |
| Fenoxaprop-P-ethyl 0.06 kg ai/ha, 10 DAS | 1 a | 0.1 a | 0.1 a | 0.2 a |
| Fenoxaprop-P-ethyl 0.09 kg ai/ha, 18 DAS | 1 a | 0.1 a | 0.1 a | 0.2 a |
| Untreated | 100 d | 5.6 efg | 11.5 e | 17.1 g |

1) DAS = Days After Seeding
2) Means followed by a common letter are not significantly different at the 5% level by DMRT

Table 2. Plant protection and dry weight of red sprangletop which were applied with several post-emergence herbicides at 30 DAS

| Treatment | Percentage of plant population | Dry weight of red sprangletop | | |
|---|---|---|---|---|
| | | root | shoot | total |
| Propanil 2.0 kg ai/ha, 8 DAS | 0 a | 0.09 a | 0.15 ac | 0.24 a |
| Propanil 2.7 kg ai/ha, 15 DAS | 92 d | 4.29 bc | 3.82 b | 8.1 bc |
| Propanil/molinate 1.5/1.5 kg ai/ha, 8 DAS | 0 a | 0.40 a | 0.46 a | 0.86 a |
| Propanil/molinate 2.0/2.0 kg ai/ha, 15 DAS | 88 d | 4.21 bc | 4.51 b | 8.72 bc |
| EPTC/2, 4 D butyl ester 1.0/0.4 kg ai/ha, 10 DAS | 60 c | 5.42 c | 5.95 bcd | 11.37 cd |
| EPCT/2, 4 D butyl ester 1.2/0.5 kg ai/ha, 18 DAS | 100 d | 10.18 d | 8.85 d | 19.03 e |
| Thiobencarb 1.25 kg ai/ha, 8 DAS | 32 b | 3.09 bc | 4.54 b | 7.63 bc |
| Thiobencarb 3.0 kg ai/ha, 15 DAS | 100 d | 8.64 d | 7.94 cd | 16.58 de |
| Thiobencarb/propanil 1.2/0.6 kg ai/ha, 8 DAS | 40 b | 3.02 b | 3.89 b | 6.91 b |
| Thiobencarb/propanil 2.4/1.2 kg ai/ha, 15 DAS | 96 d | 4.90 bc | 4.83 bc | 9.73 bc |
| Fenoxaprop-P-ethyl 0.06 kg ai/ha, 10 DAS | 0 a | 0 a | 0 a | 0 a |
| Fenoxaprop-P-ethyl 0.09 kg ai/ha, 18 DAS | 0 a | 0 a | 0 a | 0 a |
| Untreated | 100 d | 9.81 d | 7.82 cd | 17.63 de |

1) DAS = Days After Seeding
2) In a column, means followed by a common letter are not significantly different at em 5% level by DMRT

# PERFORMANCE OF RICE YIELD ON CONTINUED NO-TILLAGE SYSTEM UNDER LOWLAND CONDITION

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*Summary:* The trial was conducted at Pusakanegara Experimental Station starting from the 1993/94 upto 1996/97 wet season to evaluate the continued no-tillage system on physical and chemical soil properties as well as on rice yield under lowland condition. The trial consisted of three different groups of land preparation treatments. No-tillage without herbicide (control), no-tillage with sprayed herbicide (NTS), and full-tillage without herbicide application (FTS). The treatments were arranged in a randomized complete block design with three replications. The results indicated that NTS was applicable for lowland rice establishment under easily puddled soils whenever there was standing water. Over the seven growing seasons, NTS did not reduce rice yield compared to FTS. Changes in some physical and chemical soil properties were not effected by herbicide application, but were more related either to inorganic fertilizer application or organic matter decomposition.

*Keywords:* no-tillage rice

## INTRODUCTION

Farmers field activities for rice cultivation under lowland conditions using full-tillage system (FTS) usually starts with land cultivation. With land cultivation the soil is puddled and fields cleaned of weeds. Field cultivation, besides helping in puddling of the soil also functions as a weed control operation. Soil puddling process in some soil types could be easily achieved in flooded fields without full cultivation, and no-tillage systems (NTS) may be applicable in such conditions.

Use of no-tillage system in rice cultivation actually began when herbicides became available for killing weeds. In the last five years, at least 32 trade products consisting of nine active compounds were permitted for use in Indonesia, including glyphosate (1). In general chemical methods were more effective for weed control compared to conventional hand weeding (4). According to Bahri *et al.* (6) rice produced from no-tillage system under upland conditions reach 3.59 t/ha, and 4.61 t/ha under rainfed conditions (3), and 7.36 t/ha under lowland conditions (2). The effect of continued no-tillage system on soil physical and chemical properties and rice yield performance were investigated.

## MATERIALS AND METHODS

A series of trials were conducted at Pusakanegara Experimental Station in West-Java, Indonesia starting from 1994/95 up to 1996/97 wet season. There were eight treatments that were classified into three different groups: (1) No-tillage system without herbicide as a Control, (2) No-tillage system with 240 g/L glyphosate applied at 4 L/ha as the NTS, and (3) Full-tillage system without herbicide application as the FTS. The treatments were arranged in a completely randomized block design with three replications.

The rice was planted using the following procedure: Land was drained, blocked and separated, using bunds 30 cm wide and 25 cm high, around 10x8 m plots. At 10 days before planting, the NTS plots were sprayed with glyphosate using a semi-automatic sprayer with 400 L water solution. Three days later the field was flooded for 7 days and then after the remaining weeds were incorporated, rice IR 64 was transplanted at 25x25 cm spacing. To protect from pests and diseases, plants were treated with carbofuran at the rate of 20 kg/ha. The fertilizer used was 112.5 kg N, 22.5 kg $P_2O_5$ and 30 kg $K_2O$/ha. All of the P or K and half of N were applied at 10 days after transplanting, while the remaining N was applied at flowering stage. Weeding was carried out at 21 and 42 days after transplanting.

The effectiveness of herbicide was assessed based on data on weed dry weight, herbicide phytotoxicity, rice yield and yield components. Major soil physical and chemical properties were also observed. Influence of treatments were analyzed by anova, while differences between treatments were evaluated by DMRT.

## RESULTS AND DISCUSSION

*Weed assessment*: One week after glyphosate application or three days before transplanting rice, broad-leaved weeds (*Monochoria vaginalis, Marsilea crenata, Ludwigia octovalis* and *Salvinia molesta*), grass weeds (*Paspalum distichum, Digitaria ciliaris* and *Digitaria setigera*) and sedges (*Cyperus difformis, Cyperus iria, Scirpus juncoides* and *Fimbristilis littoralis*) were sampled and dried. Weed infestation in the rice fields were dependent on the tillage system. In the uncultivated and unsprayed plots, weed infestation was high with up to 456 $g/m^2$ of weed dry weight. On the other hand, the dry weed weights harvested from NTS or FTS plots at 14 days after transplanting was quite low, with an average of 28 $g/m^2$. Dry weed weights between NTS and FTS plots were not significantly different, except in the third and fourth planting season when the population of broad-leaved weeds increased (Table 1).

Table 1. Dry weed weights before and after transplanting rice under no- and full-tillage systems over seven planting seasons, Pusakanegara West Java-Indonesia

| | Weeds dry weights over seven planting seasons of ($g/m^2$) | | | | | | |
|---|---|---|---|---|---|---|---|
| Treatments | I | II | III | IV | V | VI | VII |
| *Before transplanting* | | | | | | | |
| Control | 229 b | 166 a | 251 a | 198 a | 238 b | 231 b | 268 b |
| NTS | 214 a | 168 a | 248 a | 205 a | 210 a | 187 a | 220 a |
| FTS | 217 a | 168 a | 256 a | 194 a | 225 b | 204 a | 214 a |
| c.v. (%) | 17.3 | 15.6 | 21.0 | 18.9 | 23.1 | 16.2 | 14.7 |
| *After transplanting* | | | | | | | |
| Control | 456 b | 264 b | 482 c | 334 c | 392 b | 348 b | 386 b |
| NTS | 15 a | 22 a | 36 b | 41 b | 28 a | 34 a | 42 a |
| FTS | 11 a | 20 a | 23 a | 22 a | 26 a | 38 a | 31 a |
| c.v. (%) | 22.6 | 27.4 | 30.1 | 19.3 | 24.8 | 22.3 | 23.0 |

NTS: No-tillage system, FTS: Full-tillage system; Values followed by the same letter are not significantly different at the 5% by DMRT.

*Soil physical properties*: Soil texture under both NTS and FTS plot did not change over the seven planting seasons. Particle sizes consisted of around 7.5% sand, 20.5% loam, and 72.0% clay. On the other hand, bulk density and porosity in some cases changed over time. The bulk density under NTS plots increased from 1.04 to 1.33 $g/m^2$, whereas porosity decreased from 62.00 to 55.38% during this period (Table 2).

Changes in the soil bulk density and porosity were attributed to soil compaction process due to no soil disturbance. Nevertheless, changes in the bulk density had no influence as yet on rice growth, as shown by plant height and tiller numbers that were not significantly different between NTS and FTS plot until the last season. Baver (5) reported that the critical value of bulk density for plant development was 1.40 $g/cm^3$.

Table 2. Soil physical properties observed over seven continuous planting seasons under no- and full-tillage systems, Pusakanegara, west Java-Indonesia

| | | Planting season | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Treatments | Soil physical Properties | I | II | II | IV | V | VI | VII |
| NTS | Bulk density (g $m^{-3}$) | 1.04 | 1.15 | 1.20 | 1.22 | 1.31 | 1.33 | 1.33 |
| FTS | | 0.92 | 0.81 | 0.92 | 0.86 | 0.90 | 0.89 | 0.91 |
| NTS | Porosity (%) | 62.00 | 59.00 | 58.20 | 57.65 | 55.46 | 55.37 | 55.38 |
| FTS | | 64.00 | 64.00 | 63.73 | 64.25 | 65.01 | 63.48 | 64.79 |
| NTS | Moisture (%) | 61.00 | 60.00 | 58.37 | 61.08 | 62.12 | 63.22 | 62.87 |
| FTS | | 62.00 | 61.00 | 60.14 | 62.32 | 62.32 | 62.87 | 63.04 |

NTS: No-tillage system, FTS: Full-tillage system

*Soil chemical properties*: Table 3 indicates that changes in some soil chemical characteristics were not influenced by tillage system, but more closely related with season, fertilization and other production inputs. Soil reaction during the dry season was usually higher than in the wet season, under both NTS and FTS plots. The results were similar for potassium status, but not for phosphorus status. Decrease in soil phosphorus status was due to no phosphorus fertilizer application during the wet season, and vice versa for potassium. It seems that weed decomposition was the reason for increasing organic carbon content and total nitrogen in NTS plots.

Table 3. Soil chemical properties over seven continuous planting seasons under no- and full-tillage, Pusaka-ne west Java-Indonesia

| Treatments | Soil chemical characteristics | Planting season I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|---|
| NTS | pH ($H_2O$) | 5.00 | 5.60 | 5.23 | 5.58 | 5.47 | 5.21 | 5.62 |
| FTS | | 5.10 | 5.60 | 5.31 | 5.67 | 5.52 | 5.33 | 5.64 |
| NTS | Organic-C (%) | 2.17 | 2.14 | 2.08 | 2.16 | 2.11 | 2.17 | 2.20 |
| FTS | | 2.14 | 2.13 | 2.05 | 2.03 | 2.00 | 2.05 | 2.13 |
| NTS | Total-N (%) | 0.27 | 0.26 | 0.31 | 0.30 | 0.28 | 0.32 | 0.33 |
| FTS | | 0.25 | 0.23 | 0.29 | 0.28 | 0.30 | 0.29 | 0.27 |
| NTS | Exch. P (ppm) | 12.04 | 11.01 | 15.44 | 13.37 | 14.46 | 13.42 | 15.22 |
| FTS | | 12.04 | 11.01 | 15.51 | 13.65 | 14.63 | 13.92 | 15.41 |
| NTS | Exch. K (me/100g) | 0.41 | 0.43 | 0.42 | 0.44 | 0.38 | 0.43 | 0.36 |
| FTS | | 0.40 | 0.46 | 0.40 | 0.48 | 0.42 | 0.44 | 0.38 |

NTS: No-tillage system, FTS: Full-tillage system

*Rice yield*: Over the seven planting seasons, rice produced from NTS plot did not show any yield decrease comp with FTS plots (Table 4). Yield fluctuation among seasons supposedly were unaffected by tillage system, but more related to yield gap between dry and wet season, that usually occurred in the north coastal areas of West including Pusakanegara. The phenomenon may be caused by: (a) high temperature in the dry season that stimu high respiration, and (b) water quality in the wet season with better nutrition than in the dry season.

## CONCLUSION

From this research it can be concluded that (i) application 240 g/L glyphosate at the rate of 4 L/ha without tillage as effective as full tillage in controlling weeds, (ii) under soil easily puddled whenever there is standing w continuous no-tillage rice cultivation up to seven seasons did not show any decrease in yield, and (iii) changes in soil chemical properties were not affected by tillage system, but were related either to inorganic fertilizer applic or organic matter decomposition.

Table 4. Yielded of IR 64 rice under no- and full-tillage systems over seven planting seasons, Pusakanegara Java-Indonesia

| Treatments | Rice yield for the season of (t/ha) I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|
| Control | 5.37 b | 4.46 b | 5.35 b | 4.26 b | 4.17 b | 4.30 b | 4.38 b |
| NTS | 7.36 a | 6.27 a | 6.95 a | 6.01 a | 5.02 a | 5.45 a | 5.93 a |
| FTS | 6.71 a | 6.29 a | 7.02 a | 6.13 a | 5.09 a | 5.36 a | 6.36 a |
| CV (%) | 10.21 | 14.50 | 9.72 | 13.46 | 18.34 | 8.70 | 8.00 |

NTS: No-tillage system, FTS: Full-tillage system; values followed by the same letter are not significantly differe the 5% by DMRT.

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# EFFECT OF PUDDLING METHOD, HERBICIDES AND ORGANIC MANURES ON WEEDS IN WET-SEEDED RICE

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*Summary:* Field experiments in wet-seeded rice were conducted during November-March and July-November seasons of 1987-88 in the wetlands of Tamil Nadu Agricultural University, Coimbatore, to investigate the influence of puddling method, herbicides and organic manures on weeds and rice. Puddling with tractor-drawn cage-wheel effectively suppressed the germination of grasses and sedges throughout the crop growth period compared to bullock-drawn mouldboard plough. Sequential application of anilofos (S (N - 4 - chlorophenyl) - N - (isopropyl - carbomoyl - methyl - O,O -dimethyl -dithiophosphate) followed by (fb) 2,4-DEE (2,4- dichlorophenoxy acetic acid (Ethyl Ester)) (0.40 fb 0.80 kg/ha) gave broad spectrum weed control. Similar results were obtained in butachlor (N-(butoxy methyl) - 2 - chloro 2'-6'- diethyl acetanilide) fb 2,4-DEE (1.00 fb 0.80 kg/ha) treatment. Higher grain and straw yields were recorded with hand-weeding twice and anilofos fb 2,4-DEE treatments in tractor-drawn cage-wheel puddled field. Neem leaf at the rate of 5 t/ha produced higher grain yield than biogas slurry and no-manure plots.

*Keywords:* wet-seeded, puddling, anilofos, 2, 4-D

## INTRODUCTION

The development of early-maturing rice varieties and improved weed management techniques have encouraged farmers to switch over to the broadcast-seeded flooded rice from traditional transplanting method. Direct seeding is extensively practiced in temperate rice-growing countries such as the USA, Australia, Italy and Portugal (4). In India 22.5 million hectares of rice area are under direct sown rice. In the past the adoption of direct seeding in flooded condition was hampered by the weed menace and absence of any viable weed control measures. Experimental evidences show that uncontrolled weed growth causes complete failure of crops. Weed competition for about six weeks in broadcast-seeded rice resulted in significant grain yield reduction (1). But when weeds are controlled properly, direct-seeded lowland rice yield as much as transplanted rice.

Weeds in direct-seeded rice could be effectively controlled by thorough land preparation, continuous submergence, hand-weeding, use of herbicides, higher seed rate or combining any two or more of these methods. An obvious benefit of tillage is suppression of weed growth. It could be considered as most important where chemical control is not in practice. Despite several advantages of hand-weeding in direct-seeded flooded rice, it has a few demerits. Due to lack of definite spacing between plants, labourers can not move easily without trampling some rice plants. Further, hand-weeding failed to uproot the stolons of grasses and tubers of nutsedge. Owing to the difficulties encountered with hand-weeding, herbicides are recommended for weed control in wet-seeded rice. However, selectivity is often narrow as the seedlings of rice and weeds are at the same stage of development. Application of organic manures in wet-seeded rice reduce the phytotoxic effect of applied herbicides on rice seedlings in addition to increased rice yield by improving soil fertility. Information available about the effect of different herbicides like anilofos, butachlor, 2,4-DEE and its mixture, their interaction with tillage and organic manures like neem leaf and biogas slurry are limited. Hence this study was undertaken and the results are presented below.

## MATERIALS AND METHODS

The experiment was laid out in strip cum split-plot design. Two vertical strips were allotted with tillage practices viz., puddling with bullock-drawn mouldboard plough and tractor-drawn cage-wheel. Horizontal strips were applied with four herbicide treatments viz., butachlor 0.75 + 2,4-DEE 0.50 kg/ha as mixture and in sequence at 1.0 kg and 0.8 kg/ha, respectively; anilofos 0.30 + 2,4-DEE 0.5 kg/ha as mixture and in sequence at 0.4 and 0.8 kg/ha, respectively. These treatments were compared with hand-weeding twice and un-weeded control. Two organic manures viz., neem leaf and biogas slurry at 5 t/ha each were compared with no-manure in the subplots of horizontal strips. The selected field was dry ploughed once uniformly with the help of bullock-drawn mouldboard plough. Then the field was flooded with water and allowed to soak for one day. The tillage treatments were performed with bullock-drawn mouldboard plough and tractor-drawn cage-wheel in horizontal strips with a buffer spacing of 0.75 meter between the treatments.

Then the vertical strips and sub-plots of horizontal strips were formed leaving 0.5 meter as buffer space around each plot.

Calculated quantities of fresh neem-leaf and biogas slurry were applied in sub-plots of horizontal strips and incorporated into the soil. The plots were leveled thoroughly and left one week for organic matter decomposition. In the case of neem cake, it was applied a day before sowing and incorporated into the soil. Pre-germinated seeds of cv. IR 60 (short duration of 110 days) at the rate of 120 kg/ha were sown uniformly in each plot having a thin film of water. Emulsifiable forms of anilofos and butachlor were applied by mixing with 50 kg/ha sand and broadcasted uniformly. The experimental plots were drained to saturated soil-moisture condition before herbicide application and the same condition was maintained for 5 days after application. A total quantity of 100 kg nitrogen and 50 kg each of phosphorus and potash were applied to the rice crop. Entire quantity of phosphorus was applied as basal in the form of single superphosphate. Potash was applied in equal splits at 20 and 80 days after sowing in the form of muriate of potash. Nitrogen was applied in three equal splits at 20, 40 and 80 DAS in the form of urea. When the crop was fully matured, border rows of 0.5 meter all around the plots were harvested first. Samples were then harvested and the grain yield was recorded after threshing, drying and cleaning, and yields adjusted to 14% moisture. Straw from each plot was sun-dried and weighed.

## RESULTS AND DISCUSSION

*Weed composition:* The predominant weeds in the first crop were sedges, which constituted 51 per cent, followed by (fb) grasses (39%) and broad-leaved weeds (BLW) (10%). The major weeds during the second crop were grasses (45%), followed by sedges (37%) and BLW (18%). In both seasons aquatics constituted only 1-2% of the total weed population.

*Weed seed population in soil:* Puddling with cage-wheel recorded less grass weed seeds in the top 15 cm of soil compared to mouldboard plough puddled field. The reduction of grass weeds in cage-wheel puddling was 24-26%. The same trend was noticed for sedges and broad-leaved weed seeds. The tubers of sedges were distributed evenly in top and sub-soil layers of bullock-drawn mouldboard ploughed puddled field. Tractor-drawn cage-wheel puddling registered more tubers in the sub-soil than the top soil. Mouldboard plough puddling recorded increased total weed seeds in the top soil compared to cagewheel puddling. In the sub-soil of 15 to 30 cm, tractor-drawn cage-wheel puddling registered higher per cent of total weed seeds compared to mouldboard plough puddling (Table 1).

*Total weed population:* Puddling method and herbicide application significantly influenced total weed numbers. The effect of organic manures on total weed number was not significant (Table.1). Puddling with tractor-drawn cage-wheel resulted in 30 to 40% less weeds compared to bullock-drawn mouldboard ploughed irrespective of the stage of observation. Puddling two times with tractor-drawn cage-wheel effectively suppressed the germination of grasses, sedges and broad-leaved weeds. This might be due to the continuous standing water in cage-wheel puddling. Impounding water in the field could be achieved by reduced hydraulic conductivity. Tractor-drawn cage-wheel puddling reduced 72 per cent hydraulic conductivity compared to bullock-drawn mouldboard plough (13). Thorough puddling increased the dry bulk density (14, 12, 8), decreased the saturated hydraulic conductivity and provided continuous standing water. The standing column of water effectively checked germination of more of grasses and moderately the sedges and broad-leaved weeds (3). In particular the emergence of *Echinocola crus-galli* (L.) Beauv., (10) and *Paspalum distichum* (Ll.) (5) were controlled by the continuous submergence. The reduced incidence of weeds in tractor-drawn cage-wheel puddled field might be also due to less viable weed seeds in the top 15 cm of soil.

Table 1. Effect of treatments on total weed population (no./m²)

| Treat | First crop (DAS) | | | | Second crop (DAS) | | | |
|---|---|---|---|---|---|---|---|---|
| | 15 | 30 | 45 | 60 | 15 | 30 | 45 | 60 |
| T1 | 28.1 | 32.7 | 47.7 | 51.7 | 40.4 | 39.9 | 53.8 | 74.9 |
| | ***5.16*** | ***5.48*** | ***6.68*** | ***6.97*** | ***6.27*** | ***6.08*** | ***7.13*** | ***8.48*** |
| T2 | 17.0 | 19.5 | 34.5 | 40.1 | 30.2 | 29.7 | 41.5 | 57.7 |
| | ***4.00*** | ***4.26*** | ***5.66*** | ***6.12*** | ***5.40*** | ***5.22*** | ***6.26*** | ***7.50*** |
| *CD(P=0.05)* | ***0.90*** | ***0.36*** | ***0.46*** | ***0.71*** | ***0.85*** | ***0.45*** | ***0.49*** | ***0.43*** |
| H1 | 9.9 | 19.6 | 34.7 | 36.8 | 23.6 | 37.1 | 52.3 | 71.7 |
| | ***3.17*** | ***4.36*** | ***5.86*** | ***6.00*** | ***4.85*** | ***6.05*** | ***7.22*** | ***8.45*** |
| H2 | 17.5 | 14.6 | 27.1 | 32.6 | 30.4 | 20.9 | 39.3 | 57.1 |
| | ***4.14*** | ***3.73*** | ***5.18*** | ***5.65*** | ***5.51*** | ***4.51*** | ***6.25*** | ***7.54*** |
| H3 | 12.9 | 21.3 | 31.9 | 38.8 | 23.9 | 36.0 | 47.3 | 68.4 |
| | ***3.59*** | ***4.62*** | ***5.61*** | ***6.19*** | ***4.79*** | ***6.00*** | ***6.87*** | ***8.26*** |
| H4 | 20.0 | 12.3 | 23.5 | 29.3 | 30.4 | 19.7 | 31.2 | 49.0 |
| | ***4.44*** | ***3.49*** | ***4.79*** | ***5.39*** | ***5.49*** | ***4.44*** | ***5.55*** | ***6.99*** |
| H5 | 36.2 | 31.6 | 34.9 | 35.3 | 51.2 | 16.8 | 20.2 | 34.8 |
| | ***5.97*** | ***5.55*** | ***5.90*** | ***5.94*** | ***7.14*** | ***4.09*** | ***4.51*** | ***5.91*** |
| H6 | 39.0 | 57.3 | 94.6 | 102.7 | 52.3 | 78.2 | 95.6 | 116.8 |
| | ***6.61*** | ***7.47*** | ***9.69*** | ***10.10*** | ***7.21*** | ***8.84*** | ***9.76*** | ***10.78*** |
| *CD(P=0.05)* | ***0.50*** | ***0.59*** | ***0.39*** | ***0.67*** | ***0.77*** | ***0.84*** | ***0.76*** | ***0.63*** |
| M1 | 22.1 | 27.5 | 42.2 | 51.1 | 36.1 | 34.5 | 48.4 | 67.7 |
| | ***4.52*** | ***5.07*** | ***6.28*** | ***6.93*** | ***5.87*** | ***5.61*** | ***6.75*** | ***8.06*** |
| M2 | 22.2 | 21.8 | 39.6 | 42.4 | 32.9 | 33.9 | 46.1 | 65.3 |
| | ***4.55*** | ***4.37*** | ***6.01*** | ***6.27*** | ***5.64*** | ***5.61*** | ***6.60*** | ***7.94*** |
| M3 | 23.4 | 29.1 | 41.5 | 44.2 | 36.9 | 35.9 | 48.5 | 66.0 |
| | ***4.66*** | ***5.17*** | ***6.23*** | ***6.44*** | ***5.98*** | ***5.75*** | ***6.74*** | ***7.96*** |
| *CD(P=0.05)* | ***NS*** | ***NS*** | ***NS*** | ***NS*** | ***NS*** | ***NS*** | ***NS*** | ***NS*** |

T1- Bullock-drawn mouldboard plough ; T2- Tractor-drawn cage-wheel; H1-Butachlor + 2,4-DEE (0.75+0.5 kg/ha); H2- Butachlor fb 2,4-DEE (1.0 fb 0.8); H3- Anilofos + 2,4-DEE (0.3 + 0.5); H4- Anilofos fb 2,4-DEE (0.4 fb 0.8); H5- hand weeding twice (20 and 40 DAS); H6-Unweeded check); M1-No manure; M2-Neem leaf (5 t/ha); M3-Biogas slurry (5 t/ha); NS- non significant. Values in bold italics are transformed.

Among the herbicides anilofos was highly effective against grasses compared to butachlor. Application of 0.4 kg anilofos recorded lesser grass weeds at 60 DAS compared to butachlor at 1.0 kg/ha. Pre-emergence application of anilofos fb either one hand-weeding or application of 2,4-DEE effectively controlled most of the weeds. This might be due to better control of grasses by anilofos, and sedges and broad-leaved weeds by hand-weeding or 2,4-DEE. Hand-weeding twice resulted in 20-60 % increase in total weeds compared to sequential application of anilofos fb 2,4-DEE. Increased weed intensity in the hand-weeding treatment was due to the difficulty in distinguishing grassy weeds from the young rice seedlings at early stages and subsequent germination of weed seeds at later stages (2). Application of anilofos or butachlor with 2,4-DEE as mixture controlled weeds only up to 30 DAS and thereafter, increase in weed population was noticed. This may be due to the germination of weeds in places where rice seedlings were killed by the herbicide mixtures. Mixture of butachlor and 2,4-DEE was not selective and caused injury to rice, when applied during the early stage of crop growth (7). Vacant spaces were taken over by weeds where rice did not grow (10). In addition to the pythotoxic effect of herbicide mixture, the loss of herbicide efficiency also caused an increase in weed population at later stages. Whereas in the sequential application of pre-emergence fb early post-emergence herbicide, subsequently germinating weeds were effectively checked by the early post-emergence herbicide (9).

At 75th DAS or later all weed control treatments were comparable with one another. Puddling and herbicide application effectively influenced total weed numbers. Application of anilofos fb 2,4-DEE in field puddled with tractor-drawn cage-wheel recorded the lowest number of weeds irrespective of stage of the crop. It was comparable with hand-weeding twice and butachlor fb 2,4-DEE under cage-wheel puddling. This was due to effective suppression of emerging weeds by thorough puddling and emerged weeds by the herbicide application.

*Dry matter production of weeds (DMP):* The poor germination of weeds in tractor-drawn cage-wheel puddled field resulted in reduced dry matter accumulation throughout the crop growth period. The cage-wheel buried weed seeds in the deeper layer of soil and also ensured continuous standing water in plots which prevented germination of weed seeds. At later stages the crop canopy was able to arrest weed growth and dry matter accumulation of weeds. On the contrary there was an increase in weed dry matter production with bullock-drawn mouldboard plough puddling which could be due to shallow tillage. Among the weed control treatments hand-weeding at 20 and 40 DAS effectively arrested dry matter accumulation. Sequential application of anilofos and 2,4-DEE recorded the minimum DMP at 30 DAS. Application of anilofos or butachlor with 2,4-DEE as mixtures were effective only at 15 DAS. Interaction between herbicide and puddling method significantly influenced DMP. Application of anilofos fb 2,4-DEE in cage-wheel puddled fields produced the lowest DMP which was at par with hand-weeding twice and butachlor fb 2,4-DEE. Integration of tillage and chemical was more effective in controlling weeds than either tillage or chemical alone (6). Increased dry weight of weeds with herbicide treatment in organic-manure applied plots might be due to adsorption of herbicide by organic matter and also faster degradation by microorganisms (Table 2).

Table 2. Effect of treatments on weed dry matter production (kg/ha)

| Treat | First crop (DAS) | | | | Second crop (DAS) | | | |
|---|---|---|---|---|---|---|---|---|
| | 15 | 30 | 45 | 60 | 15 | 30 | 45 | 60 |
| T1 | 77 | 134 | 231 | 636 | 93 | 179 | 302 | 808 |
| T2 | 50 | 84 | 143 | 401 | 55 | 97 | 206 | 495 |
| *CD(P=0.05)* | *26* | *11* | *54* | *225* | *8* | *34* | *58* | *100* |
| H1 | 53 | 120 | 217 | 571 | 53 | 185 | 284 | 636 |
| H2 | 59 | 102 | 190 | 499 | 64 | 111 | 237 | 571 |
| H3 | 47 | 109 | 183 | 488 | 48 | 150 | 257 | 561 |
| H4 | 53 | 90 | 144 | 392 | 62 | 92 | 203 | 463 |
| H5 | 83 | 40 | 29 | 86 | 108 | 39 | 32 | 166 |
| H6 | 87 | 192 | 362 | 1077 | 109 | 245 | 511 | 1511 |
| *CD(P=0.05)* | *17* | *9* | *55* | *151* | *8* | *25* | *41* | *151* |
| M1 | 64 | 104 | 176 | 497 | 76 | 136 | 240 | 601 |
| M2 | 56 | 104 | 179 | 514 | 72 | 128 | 257 | 669 |
| M3 | 72 | 119 | 206 | 545 | 73 | 151 | 265 | 684 |
| *CD(P=0.05)* | *NS* | *NS* | *NS* | *NS* | *NS* | *NS* | *NS* | *NS* |

*Grain and straw yield:* Grain and straw yields were significantly influenced by all the three weed control factors-herbicide, puddling and organic manure application (Table.3). Puddling with tractor-drawn cage-wheel increased the grain yield by 18-21 % over puddling with bullock-drawn mouldboard plough. Hand-weeding twice produced the highest grain and it was on par with anilofos fb 2,4-DEE.

Table 3. Effect of treatments on rice grain and straw yield (t/ha)

| Treat. | First crop | | Second crop | |
|---|---|---|---|---|
| | Grain yield | Straw yield | Grain yield | Straw yield |
| T1 | 3.66 | 5.29 | 3.99 | 5.73 |
| T2 | 4.61 | 5.91 | 4.68 | 6.26 |
| *CD(P=0.05)* | *0.55* | *0.61* | *0.53* | *0.57* |
| H1 | 3.79 | 5.26 | 4.09 | 5.57 |
| H2 | 4.45 | 6.01 | 4.73 | 6.39 |
| H3 | 4.03 | 5.28 | 4.19 | 5.63 |
| H4 | 4.76 | 6.05 | 5.08 | 6.51 |
| H5 | 5.17 | 6.40 | 5.44 | 7.03 |
| H6 | 2.49 | 4.61 | 2.50 | 4.83 |
| *CD(P=0.05)* | *0.42* | *0.72* | *0.50* | *0.76* |
| M1 | 3.99 | 5.44 | 4.28 | 5.88 |
| M2 | 4.34 | 5.70 | 4.48 | 6.11 |
| M3 | 4.08 | 5.66 | 4.25 | 6.00 |
| *CD(P=0.05)* | *0.25* | *NS* | *NS* | *NS* |

Anilofos applied as pre-emergence resulted in the least dry weight of weeds and grain yield similar to hand-weeding twice in wet-seeded rice (11). Butachlor fb 2,4-DEE produced yields comparable to anilofos fb 2,4-DEE. Mixtures of anilofos + 2,4-DEE and butachlor + 2,4-DEE yielded significantly lower than sequential applications due to loss of selectivity and increased weed competition at the later stage of crop growth. Neem leaf at the rate of 5 t/ha produced higher grain yield than biogas slurry and no-manure plots. Puddling with tractor-drawn cage-wheel and application of anilofos fb 2,4-DEE or hand-weeding twice were superior to other treatment interactions. Herbicides are often necessary for higher yields in direct-seeded rice even with thorough preparation of land (15). Puddling twice with tractor-drawn cage-wheel produced higher straw yield compared to puddling thrice with bullock-drawn mouldboard plough. Among the weed control methods hand-weeding twice resulted in higher straw yield and it was on par with anilofos fb 2,4-DEE and butachlor fb 2,4-DEE. The lowest straw yield was recorded in unweeded check. Application of herbicide mixtures of anilofos or butachlor with 2,4-DEE significantly reduced the straw yield than butachlor fb 2,4-DEE. Though the neem leaf at 5 t/ha recorded higher straw yield than biogas slurry, they were on par with no-manure treatment. Among the interactions, fields puddled with tractor-drawn cage-wheel and treated with anilofos fb 2,4-DEE or hand-weeding twice significantly increased straw yield than with mixture of anilofos or butachlor with 2,4-DEE. The interaction among the other factors were not significant.

*Conclusion:* Pre-emergence application of anilofos or butachlor with 2,4-DEE in sequence was highly effective against weeds compared to their individual application. Puddling twice with tractor-drawn cage-wheel as cultural method, was most efficient in suppressing all the weed species in wet-seeded rice. Organic manure increased the grain yield, but did not have any significant influence on the weed population.

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# EFFECT OF CONTINUOUS GLYPHOSATE APPLICATION ON SELECTED NUTRIENT STATUS OF ZERO-TILLED IRRIGATED LOWLAND RICE

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*Summary*: Status of selected nutrient under of continuous glyphosate application in zero-tilled irrigated lowland rice was evaluated in farmer's field at Solok, West Sumatera (Indonesia) from wet season 1994/95 to dry season 1996 (four cropping seasons). Combination of four rates and two times of glyphosate application followed by zero tillage systems, and farmer's practice (conventional tillage) were arranged in randomized complete block design with three replications. Results showed that subtitution of conventional tillage by zero-tillage systems by applying glyphosate herbicide affected soil organic-C content, total-N and available P; there was a positive growth and yield response in rice. Relatively higher rice yields were obtained than with conventional tillage, particularly in the dry season, when the herbicide was applied at 10 or 20 days before transplanting rice.

*Keywords*: soil nutrient status, zero tillage, continuous glyphosate application,

## INTRODUCTION

Conventional tillage systems are common practice in irrigated lowland rice. These systems required 20% irrigation water and increases cost of production by 25% (labour and cash), before transplanting the rice (3). Subtitution with zero-tillage systems is becoming popular with farmers due to labour shortage and limited irrigation water. Hakim *et al* (2) stressed that it was not necessary to use conventional tillage in areas with good irrigation systems. There was a need to evaluate zero-tillage for the control of weeds and previous seasons ratoon rice, as well as rice growth.

Research reports indicate that application of selected post-emergence herbicides speed up decomposition of weeds and rice ratoons, increase soil permeability, available phosphorus, cation exchange capacity, total nitrogen and organic carbon (4, 5). In addition, zero-tillage may conserve soil conditions, saves water and cash, and increases planting indices and grain yield of irrigated lowland rice (1, 3). However, with continuous zero-tillage every cropping season, the impact on nutrients and rice yields need to be monitored to ensure the system is sustainable.

Objectives of this study were to evaluate status of soil organic carbon, nitrogen and phosphorus availability as well as the trend in rice grain yield in irrigated lowland rice under continuous zero-tillage using glyphosate herbicide.

## MATERIALS AND METHODS

A field experiment was conducted in a farmer's field in Solok, West Sumatera, Indonesia from the wet season (WS) of 1994/95 to the dry season (DS) of 1996 (four cropping seasons). Area was characterized by alluvial soil with initial soil organic carbon 3.09%, total N 0.36%, undetectable phosphorus, medium altitude and semi-technical irrigation systems. Combinations of four glyphosate (Polaris 240 AS) rates (5, 6, 7 and 8 liters product per hectare) and two times of application (10 and 20 days before transplanting rice, DBT), and conventional tillage (farmer's practice) were arranged in a randomized complete block design with three replicates. Ten days after application in the 20 DBT or 5 days in the 10 DBT treatment plots water drained and then flooded to 3-5 cm depth before transplanting rice.

Twenty-one day old rice (cv. Cisokan) seedlings were transplanted in plots 4x5 m, spaced 25x25 cm apart (3 seedlings per hill). Each plot had an inlet and outlet for water control. Crops were fertilized with 200, 150 and 100 kg/ha of Urea, TSP and KCl, respectively. Recommended insecticides and fungicides were applied when symptomatic infestations appeared. Weeding was carried out at 21 and 42 days after transplanting.

Data collected were: total N, organic carbon and available phosphorus in the soil, and grain yield of rice in each cropping season.

## RESULTS AND DISCUSSION

Continuous glyphosate application in zero-tilled irrigated lowland rice did not affect soil organic carbon recorded at 60 DAT in all cropping seasons. In the first cropping season (DS 1994/95), all zero-tilled plots treated with glyphosate had higher soil organic carbon than conventional tilled plots (Table 1). The same trend was observed in succeeding seasons. Total soil nitrogen content seemed to be relatively lower in all cropping seasons for zero-tillage plots treated with glyphosate than in conventional tillage. Total soil nitrogen tended to increase with the higher rate of glyphosate applied. Available soil phosphorus also increased with increased rate of herbicide used, but were relatively lower than in conventional-tillage plots.

Grain yield of was not affected by the zero-tillage system over the four cropping seasons (Table 2). During the 1994/95 wet season, all zero-tillageplots gave relatively higher grain yield than conventional tillage. However, 6-7 L/ha glyphosate seemed to be an appropriate rate regardless of time of application. The same trend was observed in succeeding cropping seasons. Grain yield during the DS of 1995 was drastically low compared to other cropping seasons. This was due to heavy rat infestation, and the yield was significantly lower in conventional-tillage plots.

Table 1. Total organic-C and Nitrogen, and P-availability in soil at 60 DAT over the four seasons. (Solok, Indonesia, 1994-1996).

| Glyphosate (L/ha) | Time of application (DBT) | WS. 1994/95 | DS. 1995 | WS. 1995/96 | DS. 1996 |
|---|---|---|---|---|---|
| | | | Organic-C (%) | | |
| 5 | 10 | 3.24 | 2.89 | 3.19 | 2.89 |
| 6 | 10 | 3.34 | 2.59 | 2.94 | 2.69 |
| 7 | 10 | 2.99 | 3.14 | 3.09 | 3.24 |
| 8 | 10 | 3.34 | 3.34 | 2.69 | 2.69 |
| 5 | 20 | 3.34 | 2.94 | 2.79 | 3.29 |
| 6 | 20 | 3.29 | 3.39 | 2.84 | 3.39 |
| 7 | 20 | 3.89 | 3.49 | 2.84 | 3.99 |
| 8 | 20 | 3.89 | 3.34 | 3.14 | 3.50 |
| Conv. Tillage | | 2.99 | 2.94 | 2.99 | 3.39 |
| | | | Nitrogen (%) | | |
| 5 | 10 | 0.30 | 0.28 | 0.39 | 0.29 |
| 6 | 10 | 0.35 | 0.29 | 0.34 | 0.25 |
| 7 | 10 | 0.37 | 0.31 | 0.37 | 0.30 |
| 8 | 10 | 0.34 | 0.29 | 0.35 | 0.29 |
| 5 | 20 | 0.43 | 0.30 | 0.36 | 0.30 |
| 6 | 20 | 0.39 | 0.30 | 0.34 | 0.49 |
| 7 | 20 | 0.39 | 0.31 | 0.36 | 0.36 |
| 8 | 20 | 0.34 | 0.21 | 0.29 | 0.31 |
| Conv. Tillage | | 0.50 | 0.28 | 0.40 | 0.34 |
| | | | P availability (Bray II, ppm) | | |
| 5 | 10 | 18.77 | 3.96 | 5.58 | 2.73 |
| 6 | 10 | 6.79 | 7.71 | 5.54 | 3.38 |
| 7 | 10 | 6.04 | 5.46 | 5.34 | 4.44 |
| 8 | 10 | 10.54 | 3.69 | 5.72 | 7.09 |
| 6 | 20 | 13.77 | 5.46 | 5.18 | 7.26 |
| 7 | 20 | 7.24 | 3.46 | 5.60 | 7.62 |
| 8 | 20 | 13.53 | 10.72 | 5.30 | 7.79 |
| Conv. Tillage | | 6.04 | 2.46 | 5.36 | 10.80 |

Table 2. Grain yields over four seasons with glyphosate application, Solok Indonesia, 1994-1996.

| Glyphosate (L/ha) | Time of application (DBT) | Grain yield (kg/ha) WS. 1994/95 | DS. 1995 | WS. 1995/96 | DS. 1996 |
|---|---|---|---|---|---|
| 5 | 10 | 3048 a | 2267 a | 2787 a | 4167 ab |
| 6 | 10 | 2977 a | 2133 ab | 2637 a | 4380 ab |
| 7 | 10 | 3196 a | 2420 a | 3490 a | 4573 ab |
| 8 | 10 | 2991 a | 2417 a | 3297 a | 4840 a |
| 5 | 20 | 3107 a | 2550 a | 2880 a | 4667 ab |
| 6 | 20 | 3374 a | 2283 a | 2563 a | 4183 ab |
| 7 | 20 | 2946 a | 2164 ab | 2507 a | 4690 ab |
| 8 | 20 | 3009 a | 2440 a | 2923 a | 4347 ab |
| Conv. Tillage | | 2830 a | 1517 b | 2770 a | 3233 b |

Means in columns followed by a common letter are not significantly different at 5% (d.m.r.t.)

From the above results, it is clear that total soil organic carbon, nitrogen and available phosphorus were not seriously affected by the zero-tillage system. In general, grain yields of zero-tillage systems were relatively higher than conventional-tillage. The rate of glyphosate recommended is between 6.0 to 7.0 L/ha.

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# REDUCED-TILLAGE IN DIRECT-SEEDED RICE

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*Summary*: Experiments were conducted to evaluate reduced tillage in direct-seeded rice. Glyphosate at 1.08 kg ae/ha was applied to control weeds in substitution for plowing. Two days after application, water was introduced and the field was submerged for five days to moisten the soil. Pre-germinated seeds were broadcast after two passes of light puddling around the field. The normal seeding rate of 125 kg/ha proved sufficient under reduced tillage. Although initial germination was low, rice plants compensated for other yield components and final yield did not differ from the conventional method. The method was proven to be more economical and versatile.

*Keywords* : reduced tillage, zero tillage, rice.

## INTRODUCTION

Rice is one of the most important economic crops in Thailand. The country exports 6-8 million tons annually which contributes to world market share of 30% (1). Although Thailand is a major rice producing country, average yield of Thai rice is low (2.18 tons/ha) compared to average world production (3.59 tons/ha). As the country is moving toward industrialization, farm labor becomes scare and labor cost increases. It has been estimated that labor and land preparation costs for rice production accounted for 30-40% of total production cost. Investment cost for Thai rice production was 103 US$/ton whereas the average selling price was at 157 US$/ton. Any improvement which helps farmers reduce production cost, will enable Thai rice to compete more effectively in the world market

Land preparation for direct-seeded rice production in Thailand is costly and time consuming. Investment cost could be reduced through reduction in tillage operations. Hermawan *et.al.* (2) demonstrated that in addition to reducing time for land preparation, water requirement for no-till transplanted rice was 32% less than conventional method. The following studies were conducted to evaluate the possibility of reduced tillage in direct-seeded rice.

## MATERIALS AND METHODS

*No-tillage and reduced-tillage in direct-seeded rice production*: Experiments were conducted to evaluate the possibility of no-tillage and reduced-tillage in direct-seeded rice. Land preparation was substituted by the use of glyphosate at 1.08 kg ae/ha to control existing vegetation. Two to three days after spraying, water was introduced into the field and the field was kept submerged for 5 days. In the no-tillage treatment pre-germinated seeds were broadcast after flooding period whereas in the reduced-tillage treatment, two rounds of puddling were implemented before broadcasting the seeds. Information on weed control, field conditions including percent straw coverage and ground conditions were recorded.

*Optimum rate of glyphosate for controlling existing vegetation under-flooded and non-flooded conditions*: The objective of this study was to refine glyphosate rates needed for controlling weeds in standing water and in normal condition. Glyphosate at 0.72, 1.08, 1.61 and 2.12 kg ae/ha were applied using knapsack sprayer with a spray volume of 200 L/ha. Experimental design was a split-plot with 3 replications. Main plots were flooded and non-flooded conditions. Subplots were glyphosate rates. Weed control was visually evaluated at 7, 14, 30 and 60 days after application.

*Elapse time required between glyphosate application and field flooding*: The objective of this study was to determine the minimum time between glyphosate application and field flooding. Glyphosate at 1.08 kg ae/ha was applied to control existing vegetation after harvest using a knapsack sprayer with a spray volume of 200 L/ha. Water was introduced into the fields at 6, 24, 48, 96, or 168 days after application. The fields were kept flooded continuously for 14 days. Weed control was visually evaluated at 7, 14, 30 and 60 days after flooding.

*Effect of straw coverage on rice seedling germination and yield in reduce-tilled direct-seeded rice*: The objective of this study was to determine the effect of straw coverage on rice seedling germination and yield. It has been estimated that 2 tons/ha of straw would be left on the soil surface after paddy harvest. Based on this assumption, 100% straw coverage was equivalent to 2 tons/ha. Glyphosate at 1.08 kg ae/ha was applied to control existing vegetation in field plots with 100%, 75%, 50%, 25% and 0% straw coverage. Two days after application, the field was flooded for 5 days. Two rounds of puddling was implemented before broadcasting pre-germinated seeds. Experimental design was randomized complete block in 3 replications. Rice seedling germination and yield were determined.

*Importance of glyphosate for weed control in reduced-till direct-seeded rice*: The objective of this study was to evaluate the need for herbicide to control existing vegetation prior to broadcasting pre-germinated seeds. Glyphosate at 1.08 kg ae/ha was applied with knapsack sprayer with a spray volume of 200 L/ha to control existing vegetation in the field after harvest. Two days after application, the field was flooded for 5 days. Two rounds of puddling were implemented before broadcasting pre-germinated seeds. This method was compared with controlling existing vegetation with puddling at 1, 2, 4 and 6 rounds without using herbicide. Experimental design was a randomized complete block with 3 replications. Weed counts were determined at 30 days after application. Rice seedling germination and yield were evaluated.

*Optimum seeding rate for reduced-till direct-seeded rice*: The objective of this study was to determine optimum seeding rate for reduced-tillage conditions. Glyphosate at 1.08 kg ae/ha was applied with a spray volume of 200 L/ha to control existing vegetation after harvest. Two days after application, water was introduced and the field was flooded for 5 days. Two rounds of puddling were implemented before broadcasting pre-germinated seeds at rates of 63, 125, 188 and 250 kg/ha dry seed. Seedling germination and rice yield were evaluated.

## RESULTS AND DISCUSSION

*Possibility of no-tillage and reduced-tillage in direct-seeded rice* : Complete elimination of tillage in direct-seeded rice resulted in inconsistent yield (Table 1). Rice yield in locations 1-4 was acceptable whereas in locations 5-8, yields were lower than conventional-till treatment. Success of no-tilled direct-seeded rice was influenced by several factors including amount of straw coverage, flatness of the ground and weed control (Table 2). No-tillage method showed comparable yield to conventional method in fields which had low percentage of straw coverage, level surface and good weed control. These conditions were observed in locations 1 to 4. Without these conditions, poor seedling germination and low yield resulted (locations 5 to 8).

Two rounds of puddling significantly increased the chance of success of reduced-tillage in direct-seeded rice (Table 3). Puddling helped alleviate unfavorable conditions such as thick straw (observed in all locations in reduced-tillage plots in Table 4) and water logging (observed in locations 7, 9 and 10 in Table 4) that were not suitable for seedling germination. Puddling helped spread thick straw which increased soil-seed contact. It also helped flatten the soil surface to some extent. Rice yield from reduced-tillage treatment was comparable to that from conventional tillage method.

Table 1 Yield comparison between no-till direct seeded rice and conventional-till direct seeded rice

| Location | Yield (Ton/ha) | |
|---|---|---|
| | Conventional-tillage | No-tillage |
| 1 | 5.3 | 4.6 |
| 2 | 4.9 | 4.8 |
| 3 | 3.8 | 4.5 |
| 4 | 2.5 | 2.8 |
| 5 | 5.0 | 3.6 |
| 6 | 5.2 | 3.5 |
| 7 | 4.6 | 3.5 |
| 8 | 6.3 | 2.0 |

Table 2 Field conditions and weed control information in fields planted to no-till direct-seeded rice

| Location | Weed Control (%) | | straw coverage (%) | flatness |
|---|---|---|---|---|
| | pre seeding application | post seeding application | | |
| 1 | 100 | 97 | 20 | good |
| 2 | 100 | 85 | 20 | good |
| 3 | 98 | 74 | 40 | good |
| 4 | 100 | 93 | 0 | good |
| 5 | 20 | 0 | 80 | fair |
| 6 | 10 | 20 | 70 | poor |
| 7 | 100 | 38 | 20 | good |
| 8 | 20 | 50 | 50 | poor |

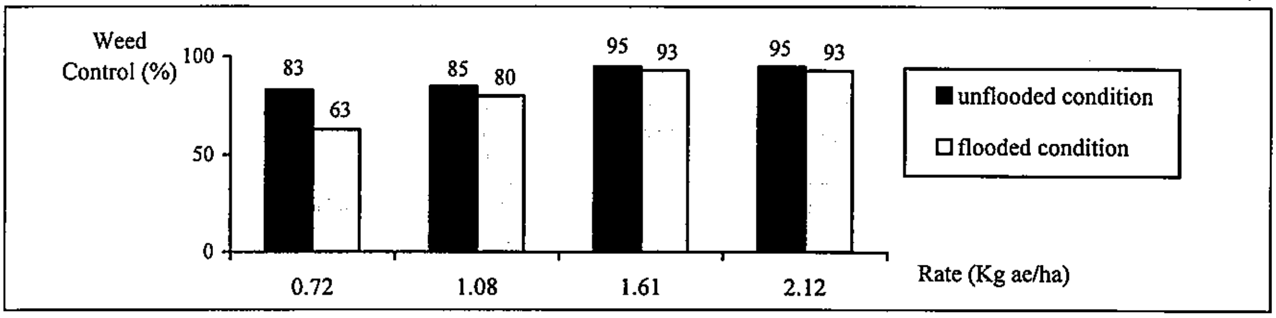
Table 3 Yield comparison between reduced-till direct-seeded rice and conventional-tilled direct-seeded rice

| Location | Yield (Ton/ha) | |
|---|---|---|
| | Conventional-till | Reduced-till |
| 1 | 5.6 | 6.1 |
| 2 | 5.6 | 6.8 |
| 3 | 6.3 | 6.8 |
| 4 | 5.3 | 5.6 |
| 5 | 5.6 | 5.6 |
| 6 | 5.3 | 5.6 |
| 7 | 6.3 | 6.3 |
| 8 | 4.4 | 4.4 |
| 9 | 5.0 | 5.0 |
| 10 | 5.3 | 5.3 |

Table 4 Field condition and weed control information in reduced-till direct-seeded rice

| Location | Weed Control (%) | | straw coverage (%) | Ground flatness |
|---|---|---|---|---|
| | pre seeding application | post seeding application | | |
| 1 | 90 | 80 | 70 | good |
| 2 | 90 | 85 | 60 | good |
| 3 | 85 | 80 | 60 | good |
| 4 | 85 | 70 | 60 | good |
| 5 | 95 | 75 | 40 | good |
| 6 | 100 | 70 | 60 | good |
| 7 | 95 | 70 | 60 | fair |
| 8 | 100 | 75 | 60 | good |
| 9 | 85 | 70 | 50 | fair |
| 10 | 90 | 70 | 60 | fair |

*Optimum rate of glyphosate for controlling existing vegetation in reduced-tillage direct-seeded rice under flooded and non-flooded condition*: Glyphosate at 0.72 kg ae/ha showed acceptable control of *Echinochloa crus-galli*, *Oryza sativa* and *Cyperus difformis* under non-flooded condition (Fig.1). However, when the herbicide was applied to weeds in standing water a minimum rate of 1.08 kg ae/ha was required for acceptable control of weeds. Higher rates did not show much difference in efficacy. Under normal condition broad-leaved weeds are not a serious problem but in locations where infestation from broadleafs is high, a higher glyphosate rate or mixture with broadleaf herbicide may be required.




Weeds: *Echinochloa crus-galli*, *Oryza sativa* and *Cyperus difformis*
Figure 1. Efficacy of glyphosate for weed control in reduced-tillage situations.

*Elapse time required between glyphosate application and field flooding*: A minimum of 24-48 h elapse time between glyphosate application and field flooding was required for acceptable control of *Echinochloa crus-galli, Cyperus difformis* and *Oryza sativa* (Fig. 2). Introduction of water at 6 h after application might wash glyphosate off from treated leaves. The amount absorbed might be poorly translocated because the weeds were under stress due to flooding. Introduction of water at 24-48 h, after sufficient amount of glyphosate had translocated to other plant parts, resulted in better control of weeds.

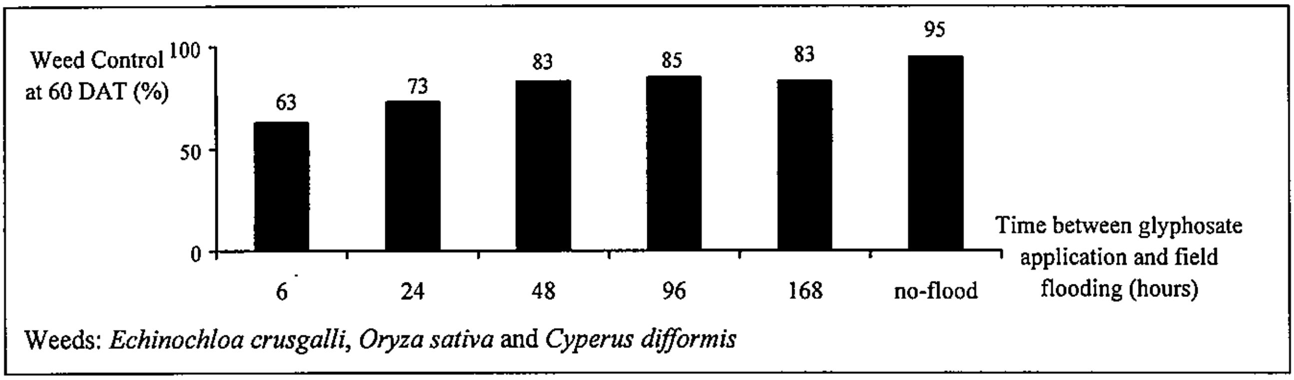



Figure 2. Efficacy of glyphosate for weed control after flooding the field at different times after glyphosate application.

*Effect of straw coverage on rice seedling germination and yield*: Amount of straw coverage affected the number of rice seedling germination (Fig. 3). Under reduced-tillage situation, the number of seedlings germinating gradually declined as the amount of straw coverage increased. Although seedling germination was less under reduced-tillage situation, panicles per m$^2$ and final yield were not significantly different from conventional method (Fig. 4). Yield from no-till plots with 100% straw coverage was lower than other treatments, although not statistically significant.

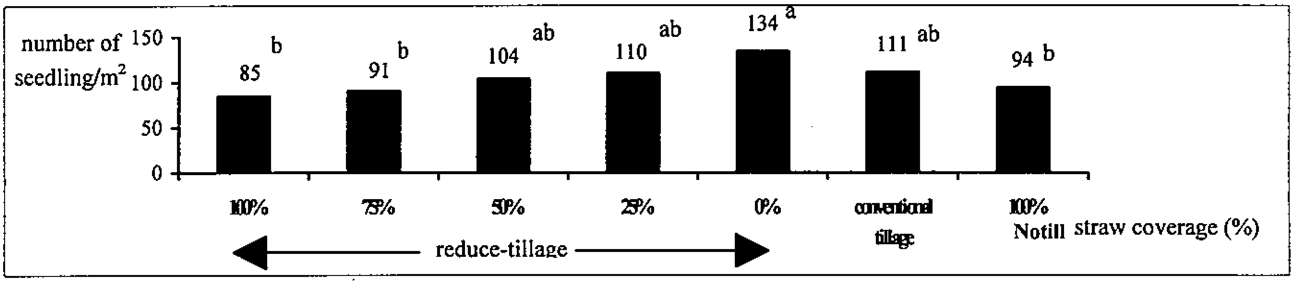



Figure 3. Effect of straw coverage on rice seedling germination under reduce-tillage situation.

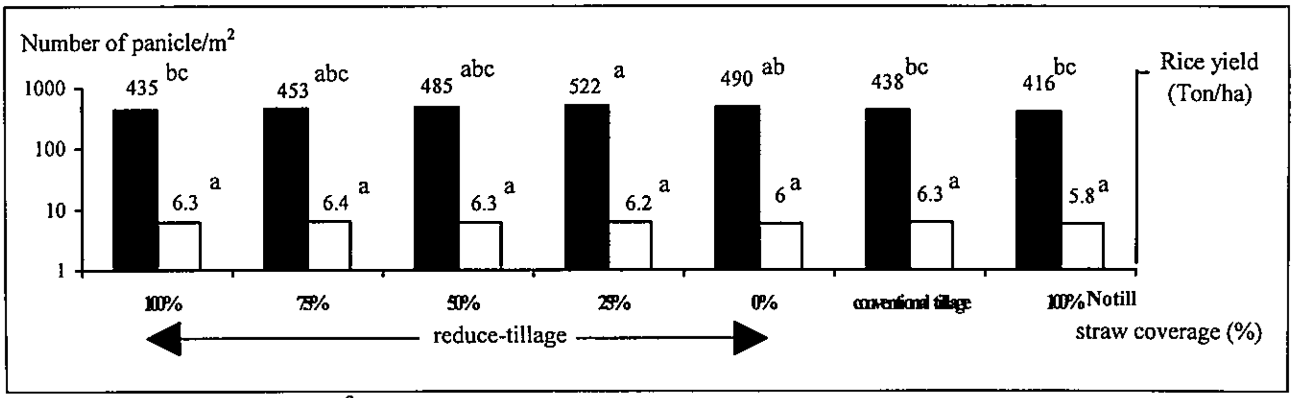



Figure 4. Number of panicle/m$^2$ and yield of paddy growing under different straw coverage.

*Importance of glyphosate for weed control in reduced-till direct-seeded rice*: The use of glyphosate as pre-broadcast treatment in reduced-tillage practice provided excellent control of *Echinochloa crus-galli* and *Leptochloa chinensis* (Fig. 5). Weed control was comparable to that obtained from conventional method. Puddling alone showed poor control of weeds. Puddling 6 rounds, besides being too time consuming, was not sufficient to provide complete control of weeds. Rice seedling germination was highest in conventional tillage treatment followed by reduced-tillage treatment (Fig.6). In reduce-tillage without glyphosate, although initial seedling germination was high in plots puddled for 6 rounds, rice seedling hardly survived due to severe competition from weeds that regrew after puddling. Rice yield from reduced-tillage using glyphosate was comparable to that obtained from conventional tillage method and significantly higher than other treatments. (Fig. 7).

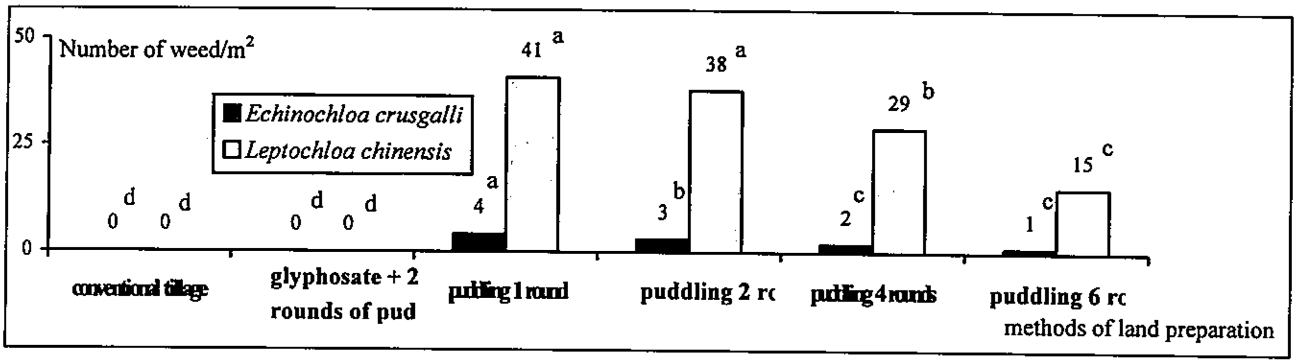



Figure 5. Numbers of weeds at 30 days after different methods of land preparation.

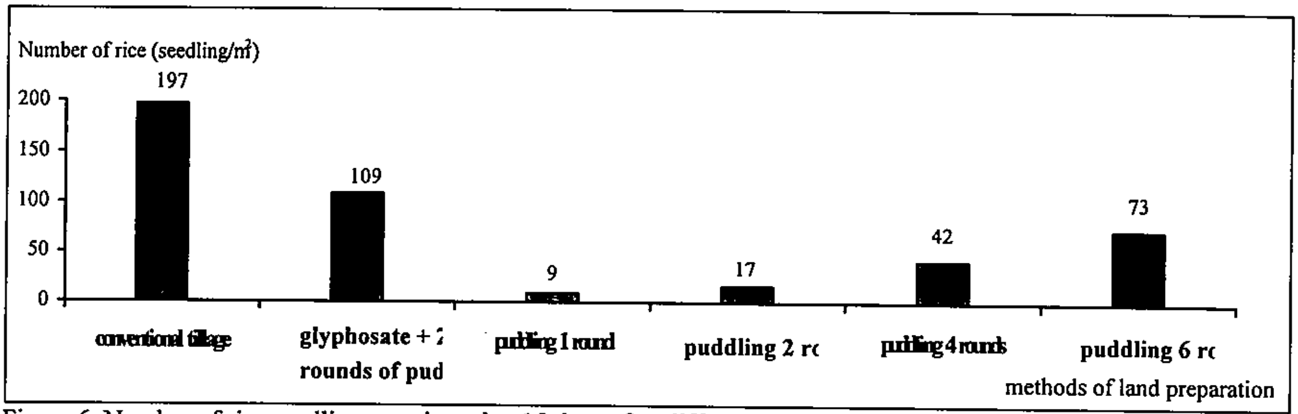



Figure 6. Number of rice seedling germinated at 15 days after different methods of land preparation .

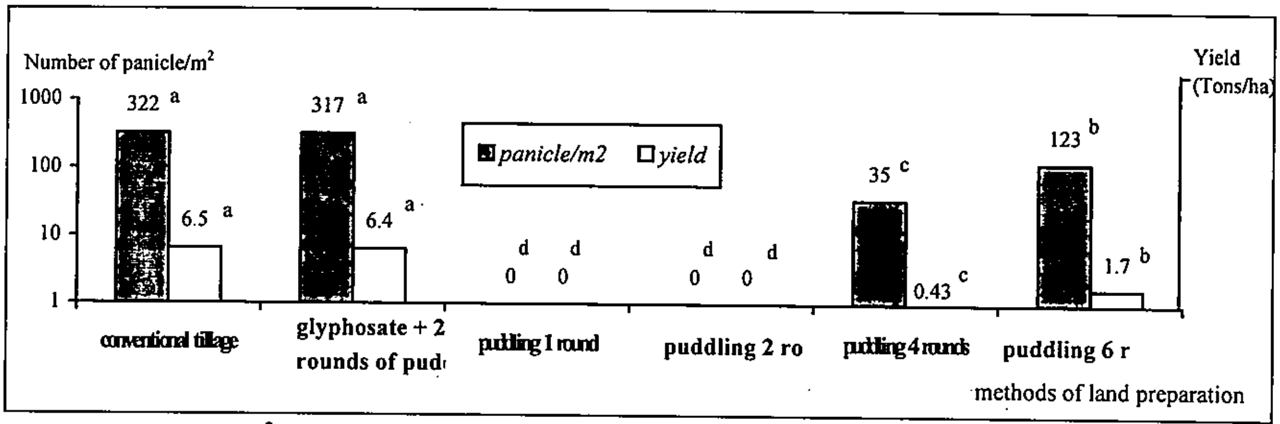



Figure 7. Rice panicle/m² and yield from different methods of land preparation.

*Optimum seeding rate for reduced-till direct-seeded rice*: Reduced-tillage technique did not require higher seeding rate than the conventional practice at 125 kg/ha. Although the initial rice germination in reduced-tillage plot was less than conventional tillage, final yield was not different (Fig. 8 and 9).

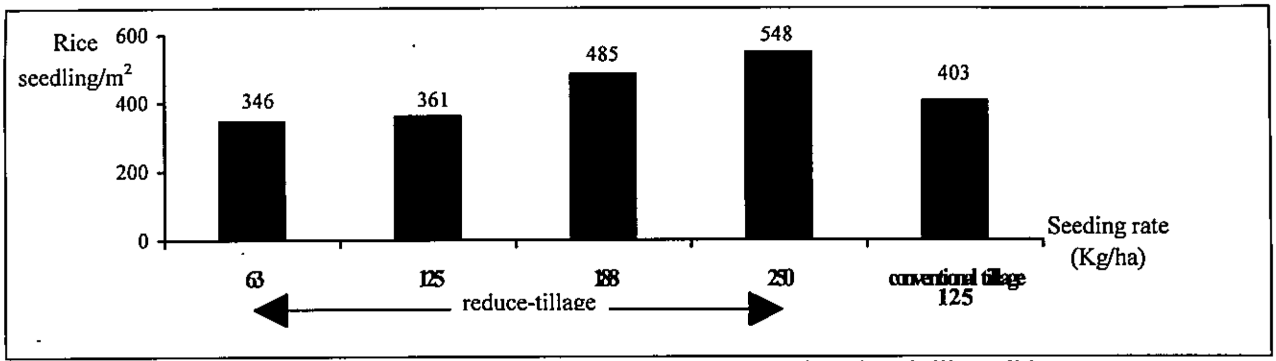



Figure 8. Number of rice seedling germination from different seeding rates in reduced-till condition.

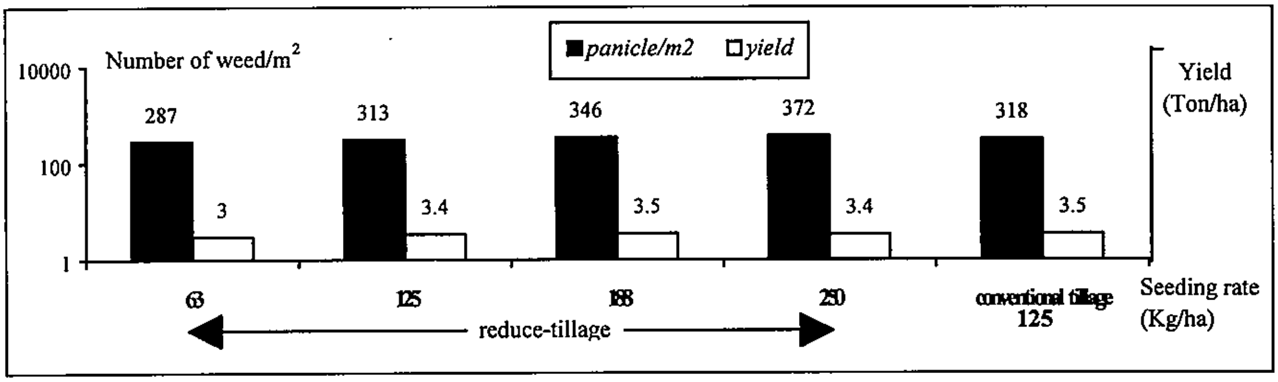



Figure 9. Panicle/m$^2$ and yield of reduced-till direct-seeded rice sown with different seeding rate.

Based on the results above, a technique for reduced-tillage in direct-seeded rice can be developed (Figure 10). Glyphosate at 0.81 kg ae/ha is recommended for controlling existing vegetation after crop harvest. Application of glyphosate should be delayed until sufficient population of weeds have emerged. Twenty-four to forty-eight hours after application water is introduced and the field is kept submerged for 5 days. Field flooding period can vary depending on soil moisture status. If plenty of moisture already exists in the soil, 2-3 days of field flooding could be enough. Reduced-tillage in direct-seeded rice does not require higher seeding rate than conventional tillage. The normal seeding rate of 125-188 kg/ha (dry seed) has been shown to be sufficient. Before broadcasting pre-germinated seeds, two rounds of puddling must be implemented. Herbicide application is required for effective weed control. Butachlor + propanil at 0.75+0.75 kg/ha sprayed at 6-7 days after seeding demonstrated good weed control. Other management practices are the same as the conventional tillage system. The reduced-tillage method has been introduced to farmers for direct-seeded rice in the central plain in Thailand. The method has been proven to be more economic and versatile by large farm owners.

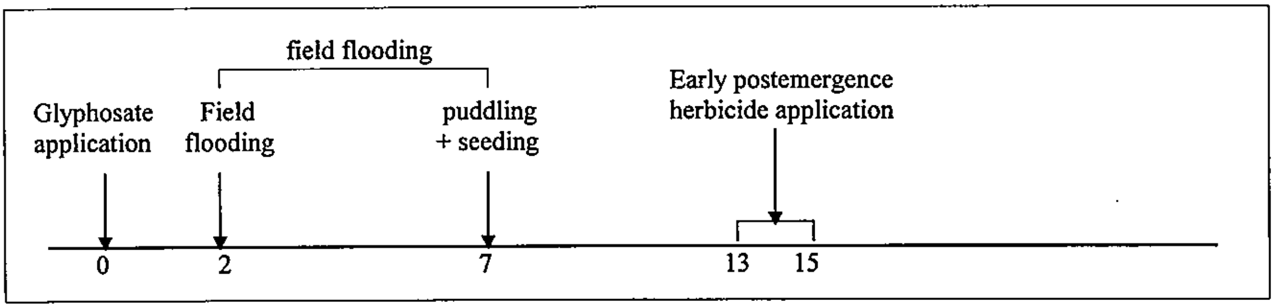



Figure 10. Procedures for reduced-till direct-seeded rice.

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2. Hermawan W., M Utomo, W.S. Ardjasa and S. Abdulrachman. Proc.15th Asian-Pacific Weed Sci. Soc. Conf. 1995. pp. 682-688.

# THE ECONOMICS OF WEED CONTROL IN TIDAL SWAMPS

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*Summary*: Weeds are one of the most serious problems of food crop cultivation in tidal swamp areas, particularly when crop establishment is practised under zero-tillage method. Herbicide application for weed control offers more cost effective alternative. To determine the effect of herbicides and it's combination a field experiment was conducted at farmer's field in Tarantang South Kalimantan in 1995/96. Two herbicides (2,4-D amine and propanil) were applied at 21-days after transplanting as main plots, and three combination of herbicides at the rate of 4, 5 and 6 L/ha were applied at 14-days before transplanting (zero-tillage method) as sub-plots. Farmer's practise was also included for comparison. The results showed that glyphosate +2,4-D (240/120) AS (Bimastar), glyphosate +2,4-D (120/120) AS (Knockout) and glyphosate +2,4-D (120/240) AS (Kombat) effectively suppressed the growth of weeds such as *Eleocharis retroflexa, E. dulcis, Fimbristylis griffithii and Leersia hexandra.* These combination herbicides can be recommended to control weeds in no-till rice in tidal swamps. The most effective treatment was the application of glyphosate +2,4-D (120/240) AS, 6 L/ha pre-plant and propanil (360 EC) 5 L/ha at post-planting. As compared to conventional weed control methods, herbicides offer advantages in terms of reduced cost of labor, proper planting time and extensive cultivation. Using herbicides required only 9 MD/ha, at the cost of Rp 63.000/ha while conventional methods required 35 MD/ha and the cost was Rp 227.500/ha

*Keywords*: economics, tidal swamp rice

## INTRODUCTION

Weeds can be defined as plants growing where they are not wanted and may occasionally affect humans directly in terms of interference to growth of useful plants. However, in a ecological sense, weeds are plants that are well adapted to the prevailing conditions. Weeds reduce agricultural output and/or add to the cost of production and are therefore important economically. Weed control and economics are inseparable in an agricultural production context and the economic effects of weeds are diverse and complex (1).

Weeds are one of the most serious problems in crop cultivation in tidal swamps. Competition from weeds to economic crops is particularly severe during crop establishment and consequently reduce yield. Rapid growth of weeds affect land preparation and plant growth. In addition weeds serve as hosts for pests and deseases and therefore must be controlled.

Weed management and land preparation by farmers in swampy areas are mostly done manually. Weeds are cut using a simple tool called "tajak" that requires a lot of labour, time and is costly. The use of herbicides to control weeds is a possible alternative for land preparation andweed control during crop establishment.

This paper describes the economic impact of weeds and assessment of their control.

## MATERIALS AND METHODS

Experiment was conducted at farmers' field in Tarantang village, Barito Kuala district of South Kalimantan in 1995/96, using a split-plot design with three replications. Two herbicides namely 2,4-D amine and propanil were treated as main-plot. The sub-plot consisted of eight treatments of each herbicide including farmers method using glyphosate + 2,4-D (Table 1). The sub-plot herbicides were applied at 14-days before transplanting and application for the main plots was at 21-days after transplanting. IR66 was transplanted (21-day old seedlings), in 7.5x7 m plots at 22x20 cm spacing. Each plot received 1 t/ha lime applied one week before transplanting together with 90 kg N, 60 kg $P_2 0_5$ and 50 kg $K_2 0$/ha. Half of the nitrogen and all P and K were applied at the time of transplanting and the other half of the nitrogen 30 days later. Furadan 3 G at 17 kg/ha was applied to control pests.

Weeds were recorded at three times: before apply herbicides, before transplanting or 14 days after application and 57 days after transplanting. Observation on phytotoxicities was recorded at seven days after herbicide application using a 0 to 5 scale. Number of tillers, yield components, production, costs and returns were evaluated and analyzed.

Table 1. Herbicide treatments to control weeds in acid sulphate soil, S. Kalimantan

| Main-plot | Sub-plot | Symbol |
|---|---|---|
| A. 2,4-D amine 865 g/L at 1 L/ha | 1. glyphosate + 2,4-D 240/120 g/L 4 L/ha | A1 |
| | 2. glyphosate + 2,4-D 240/120 g/L 5 L/ha | A2 |
| | 3. glyphosate + 2,4-D 240/120 g/L 6 L/ha | A3 |
| | 4. glyphosate + 2,4-D 120/120 g/L 5 L/ha | A4 |
| | 5. glyphosate + 2,4-D 120/120 g/L 6 L/ha | A5 |
| | 6. glyphosate + 2,4-D 120/240 g/L 5 L/ha | A6 |
| | 7. glyphosate + 2,4-D 120/240 g/L 6 L/ha | A7 |
| | 8. Farmer's method | A8 |
| B. Propanil 360 g/L at 5 L/ha | 1. glyphosate + 2,4-D 240/120 g/L 4 L/ha | B1 |
| | 2. glyphosate + 2,4-D 240/120 g/L 5 L/ha | B2 |
| | 3. glyphosate + 2,4-D 240/120 g/L 6 L/ha | B3 |
| | 4. glyphosate + 2,4-D 120/120 g/L 5 L/ha | B4 |
| | 5. glyphosate + 2,4-D 120/120 g/L 6 L/ha | B5 |
| | 6. glyphosate + 2,4-D 120/240 g/L 5 L/ha | B6 |
| | 7. glyphosate + 2,4-D 120/240 g/L 6 L/ha | B7 |
| | 8. Farmer's method | B8 |

## RESULTS AND DISCUSSION

Dorminant weeds recorded before herbicide application: (1) *Eleocharis dulcis*, (2) *Eleocharis retroflexa*, (3) *Fimbristylis griffithii* and (4) *Leersia hexandra*. These weeds were found to be abundant. Weed situation changed and the coverage decreased after herbicide application at all herbicide levels except farmers' method (Table 2). Zero tillage with herbicides effectively reduced weeds in swampy areas. Observations on herbicide toxicities showed no toxicities resulted.

These herbicides with glyphosate and 2,4-D have broad spectrum effective control of established weeds (2, 3).

Table 2. Weed coverage before herbicide application, 14-days after application, 57 days after transplanting and toxicities (35 days after transplanting) on rice in acid sulphate soil, Tarantang, S. Kalimantan.WS 1995/96

| Treat-ment | Before application | 14 days after application | 57 days after application | Toxicities | Treatment | Before application | 14 days after application | 57 days after application | Toxicities |
|---|---|---|---|---|---|---|---|---|---|
| A1 | 4 | 1 | 2 | 0 | B1 | 4 | 1 | 2 | 0 |
| A2 | 4 | 1 | 1 | 0 | B2 | 4 | 1 | 2 | 0 |
| A3 | 4 | 1 | 1 | 0 | B3 | 4 | 1 | 2 | 0 |
| A4 | 4 | 1 | 2 | 0 | B4 | 4 | 1 | 2 | 0 |
| A5 | 4 | 1 | 2 | 0 | B5 | 4 | 1 | 1 | 0 |
| A6 | 4 | 1 | 2 | 0 | B6 | 4 | 1 | 1 | 0 |
| A7 | 4 | 1 | 1 | 0 | B7 | 4 | 1 | 1 | 0 |
| A8 | 4 | 2 | 3 | 0 | B8 | 4 | 2 | 3 | 0 |

Coverage :1=very rare 2=rare 3=inherent 4=abundant
Toxicity: (0-5 level) 0= no toxicity 1= light 2=medium 3=heavy 4=very heavy 5=totally toxic

The effect of herbicides on plant growth were also evaluated. Results showed that the capacity of rice plants to produce tillers with the application of herbicides was higher than with farmers method. This was due to less competition to rice plants by weeds (Table 3). The weeds in the conventional method (weeds controlled manually) recovered earlier than with herbicides. The highest number of tillers were recorded with A4 and B5 herbicide levels and the highest number of panicles with A6 and B3 herbicide levels.

Although there was no significant effect of herbicide levels on the yield, the results showed that yield gained with the use of all herbicide levels were higher than farmers' method. The highest yield obtained with the use of A7 level (glyphosate +2,4-D (120/240) g/L, 6 L/ha) was 4.12 t/ha. With the B7 level (glyphosate +2,4-D (120/240) g/L, 6 L/ha) the yield was 5.17 t/ha. These yields were much higher than farmers' method with only 2.6 t/ha (Table 3)

Table 3. Effect of herbicides on the number of tillers, number of panicles and yield of rice in acid sulphate soil, Tarantang, S.Kalimantan WS 1995/96

| Treatment | number of tillers | number of panicles | Yield (t/ha) | Treatment | number of tillers | number of panicles | Yield (t/ha) |
|---|---|---|---|---|---|---|---|
| A1 | 21,93ab | 69,93ab | 3,42bc | B1 | 22,27a | 86,27b | 2,29ab |
| A2 | 23,93a | 71,53ab | 4,07cd | B2 | 22,40a | 66,47ab | 3,61bc |
| A3 | 23,87a | 81,60b | 2,71ab | B3 | 21,93ab | 112,73c | 3,92cd |
| A4 | 24,27a | 90,67b | 3,08ab | B4 | 22,33a | 85,07b | 3,47bc |
| A5 | 23,60a | 88,40 | 3,69bc | B5 | 24,33a | 90,27b | 4,38bc |
| A6 | 23,80a | 109,67c | 3,27c | B6 | 22,87a | 93,53b | 3,84cd |
| A7 | 23,27a | 87,33b | 4,12cd | B7 | 23,53a | 111,93c | 5,17e |
| A8 | 18,00b | 58,87a | 2,56a | B8 | 20,07b | 47,60a3 | 2,65a |

Highest net-income was gained from the combination treatments of A7 and B7, which were Rp 1.7 million and Rp 2.1 million/ha respectively. This income was derived after deducting 10% for yield correction, cost of herbicides and labour (Table 4). Results in Table 4 also indicate that the cost of conventional weed control was more than with the herbicides.

Table 4. Economic analysis of herbicides used for weed control in tidal swamp areas, South Kalimantan, 1995/96

| No | Treatment[a] (Herbicides) | Yield (t/ha) | Correction 10 % | Income[b] (Rp.000) | Cost Rp.(x1000)[c] | | | Total Cost (Rp.000) | Net Income (Rp.000) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Hrb | Apl. | Clearing[d] | | |
| A1 | Lind/Bim 4 l/ha | 3,42 | 3,078 | 1.539,0 | 62.5 | 17.85 | 41,15 | 121,5 | 1.417,5 |
| A2 | Lind/Bim 5 l/ha | 4,07 | 3,663 | 1.831,5 | 75.0 | 17.85 | 41,15 | 134,0 | 1.697,5 |
| A3 | Lind/Bim 6 l/ha | 2,71 | 2,439 | 1.219,5 | 87.5 | 17.85 | 41,15 | 146,5 | 1.073,0 |
| A4 | Lind/Kno 5 l/ha | 3,08 | 2,772 | 1.386,0 | 75.0 | 17.85 | 41,15 | 134,0 | 1.252,0 |
| A5 | Lind/Kno 6 l/ha | 3,69 | 3,321 | 1.660,5 | 87.5 | 17.85 | 41,15 | 146,5 | 1.514,0 |
| A6 | Lind/Kom 5 l/ha | 3,27 | 2,943 | 1.471,5 | 75.0 | 17.85 | 41,15 | 134,0 | 1.697,5 |
| A7 | Lind/Kom 6 l/ha | 4,12 | 3,708 | 1.854,0 | 87.5 | 17.85 | 41,15 | 146,5 | 1.707,5 |
| A8 | Farmer | 2,56 | 2,304 | 1.152,0 | - | - | (227,5) | 227,5 | 924,5 |
| B1 | Lind/Bim 4 l/ha | 2,92 | 2,628 | 1.314,0 | 112.5 | 17.85 | 41,15 | 171,5 | 1.142,5 |
| B2 | Lind/Bim 5 l/ha | 3,61 | 3,249 | 1.624,5 | 125.0 | 17.85 | 41,15 | 184,0 | 1.440,5 |
| B3 | Lind/Bim 6 l/ha | 3,92 | 3,528 | 1.764,0 | 137.5 | 17.85 | 41,15 | 196,5 | 1.567,5 |
| B4 | Lind/Kno 5 l/ha | 3,47 | 3,123 | 1.561,5 | 125.0 | 17.85 | 41,15 | 184,0 | 1.377,5 |
| B5 | Lind/Kno 6 l/ha | 4,38 | 3,942 | 1.971,0 | 137.5 | 17.85 | 41,15 | 196,5 | 1.774,5 |
| B6 | Lind/Kom 5 l/ha | 3,84 | 3,456 | 1.728,0 | 125.0 | 17.85 | 41,15 | 184,0 | 1.544,0 |
| B7 | Lind/Kom 6 l/ha | 5,17 | 4,653 | 2.326,5 | 137.5 | 17.85 | 41,15 | 196,5 | 2.130,0 |
| B8 | Farmer | 2,65 | 2,385 | 1.192,5 | - | - | (227,5) | 227,5 | 965,0 |

[a]Lind=Lincosin; Bim=Bimastar; Kno=Kockout Kom=Kombat; Prop=Propatox These are registered trade marks of PT. Bima Kimia Nufarm

[b]Price of rice (unhusk) Rp 500/kg

[c]Hrb=Herbicide price Apl=Application Cost (Rp 7000/MD for 2.55 MD/ha) Clearing =Cost of clearing (Rp7000/MD for 5.88 MD/ha)

[d]Figure in parentheses mean clearing with Tajak, a traditional tool (35 MD/ha, Rp 6500/MD)

There are several possible alternatives or strategies to adopt in weed control. All strategies must be carefully defined in terms of their spatial and temporal aspects as this will affect cost as well as income. From the economic point of view, the use of herbicides to control weeds can be recommended particularly in areas with lack of labor and where farming costs are high.

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# WEED CONTROL USING A BLANKET WIPER

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*Summary:* The technique of using a chemical (herbicide) impregnated blanket for applying non-selective products to tall-growing weeds in crops and pastures has been available for some time. The success of this technique has been limited to some extent by the cost of materials, particularly the blanket. Ranges of materials for the blanket were tested. Using readily available irrigation fittings reduced the cost of constructing the unit. In addition various materials were evaluated to select a suitable backing for the blanket to give it greater strength and durability. The wiper unit incorporates adjustable springs to allow tensioning, to accommodate various weed species and densities. Testing with herbicides such as glyphosate, chlorsulfuron, metsulfuron-methyl and 2,4-D has given good control of bracken *Pteridium esculentum*, Paterson's curse *Echium plantagineum*, cape tulip *Homeria* spp., Guildford grass *Romulea rosea* and Parramatta grass *Sporobolus indicus* var *capensis.* The wiper could be used on roadsides and on a range of horticultural and plantation weeds in tropical countries.

*Keywords*: blanket wiper, weed wiper

## INTRODUCTION

Selectively applying herbicides to taller plants is not a new concept. In the 1970s, after the introduction of glyphosate, there was considerable interest in the USA for selectively treating tall grasses using rope wick applicators in cotton and soybean (2) and for weed control in developing countries (10). While these generated interest in Australia, the commercial units were not well received because they were extremely expensive, had slow operating speeds and were not robust in construction (4). In Western Australia it was also shown that control of bracken *Pteridium esculentum* (Forst. f.) Cockayne varied according to the different rope configurations used (3). Other methods to selectively apply herbicides to taller weeds such as using belt rollers have also been investigated (9, 11), but like the rope wick applicators they have yet to gain wide commercial acceptance. More recent research in the Northern Territory of Australia has indicated that a herbicide roller unit, described in Anon. (1), gave control of sida *Sida acuta* Burm. f., flannel weed *S. cordifolia* L., sicklepod *Cassia obtusifolia* L. and some eucalypts *Eucalyptus* spp. in legume and grass pastures (5).

A more practical design using a brush or blanket wiper has been available for some years and shown to be effective (12, 13) but this design has also had a fairly low level of acceptance maybe because of experiences gained during the era of the rope wick applicator. Tests conducted in Western Australia using various fabric materials for the blanket have resulted in a much cheaper version of the blanket wiper (6, 7). The blanket uses a cheap, readily available upholstery fabric. Liquid flow is controlled from a monitor that can vary the length of time that liquid can be injected into the blanket in a pulse, as well as the number of pulses in a given time. Speeds up to 12 km/hr have been tested on some weed species with no loss of efficiency, with volumes of application 5 L to 28 L/ha, which is considerably lower than the 200-400 L/ha that was used in tests during the late 1980s and early 1990s in eastern Australia (12).

This paper complements the poster (8), which deals with the construction and operation of a blanket wiper developed at Agriculture Western Australia.

## MATERIALS AND METHODS

Treatments were applied to bracken and one and two leaf cape tulip *Homeria flaccida* Sweet and *H. miniata* (Andrews) Sweet, respectively.

*Experiment 1. Bracken control in pasture*: Treatments were applied 17 June 1994 using a blanket wiper described by Rayner (6) and a conventional boomsprayer. Plot size was 4x50 m, in an unreplicated experiment. Blanket wiper treatments were glyphosate 2700 g a.i./ha + metsulfuron-methyl 18 g a.i./ha applied as a single pass or 5400 g a.i./ha + 36 g a.i./ha using two passes. The volume of application for the single pass was 30 L/ha, the double 60 L/ha. Speed of application was 6 km/h. Boomsprayer treatments were: glyphosate 1350 g a.i./ha, metsulfuron-methyl 18 g a.i./ha, glyphosate 900 g a.i./ha + metsulfuron-methyl 18 g a.i./ha using a volume of application of 140 L/ha at a speed of 8 km/hr. Visual assessment of frond damage and subterranean clover *Trifolium subterraneum* L. pasture damage was taken on 16 May 1995 and frond counts/m taken on 18 December 1995.

*Experiment 2. Cape tulip (one and two leaf) control in pasture*: Blanket wiper treatments were applied on 30 September 1995 using metsulfuron-methyl at 0.3 and 3 g a.i./ha or in combination with 112.5, 225 and 450 g a.i./ha glyphosate. Speed of application was 8 km/h in a single pass delivering 5 L/ha of solution. Three replications were used in a randomised complete block design.

Cape tulip counts for 10 quadrats (50x50 cm) were taken on 28 June 1996 and values converted to percentage reduction for one leaf cape tulip. A visual pasture assessment for cape tulip was carried out for plant composition converted to percentage reduction.

## RESULTS AND DISCUSSION

*Experiment 1. Control of bracken*: From the visual assessments taken the year the treatments were applied, no subterranean clover damage was noted on the blanket-wiped treatments compared to the 50% and 65% reduction in subterranean clover on the booms-prayed applications. Although no equivalent rates of chemical were used, that would allow direct comparison of the boom-spray and blanket-wiped treatments, there is an indication that with refinement the blanket wiper could be quite useful in areas where the timing of treatments coincides with growth of annual pastures (Table 1). Selectively wiping glyphosate plus metsulfuron-methyl onto the taller growing bracken, effectively reduced its competitiveness with shorter growing pasture, for light, nutrients and moisture.

The results for bracken control, even though not from a replicated experiment, are consistent with those recorded by Moore and Jones (3) using a rope-wick applicator and Young (13) using a commercial blanket wiper (Weeds Wiper®). Because Young (13) quoted the dilution of the herbicide with water, it was difficult to make a comparison of the actual amount of chemical being used over a given area. The delivery system on the blanket wiper used in the Western Australian research gives measured pulses of liquid which can be converted to amounts per hectare, thus measuring chemical usage per hectare.

*Experiment 2. Control of Cape tulip*: Significant reductions in both one and two leaf cape tulip were obtained using the blanket wiper to apply as little as 0.3 g a.i./ha of metsulfuron-methyl, either alone or in combination with glyphosate (Table 2). Increasing the rate to 3.0 g a.i./ha improved control, however the addition of glyphosate had little effect on cape tulip reductions at both the 0.3 g a.i./ha and 3.0 g a.i./ha rates. Both metsulfuron-methyl and chlorsulfuron have activity on cape tulip, but their wide use in pasture when applied by boom-spray is not favoured because of the damage caused to the legume component (mainly subterranean clover) of annual pastures. Results similar to those presented for metsulfuron-methyl have been recorded for chlorosulfuron applied through the blanket wiper (J. Peirce and B. Rayner, unpublished results). The possibility of using these products to replace the boom-spray applications of 2,4-D amine/ester, which also lead to a decline in subterranean clover and dominance of grasses in pastures after several years of use, could be of considerable value. The use of 2,4-D amine/ester through a blanket wiper also gives control of cape tulip (J. Peirce, unpublished results).

## CONCLUSIONS

The blanket wiper described here has the potential advantage of controlling tall weeds with less herbicide than conventional boom-sprayers, and without damaging desirable pasture plants.

Preliminary results indicate that the fabric used for the construction of the blanket and the method of attaching the blanket are robust enough for use on a range of weeds. The delivery system is accurate, because it can regulate the amount of chemical by the length of time the control valve is opened to release liquid to the blanket and the number of pulses or times the valve is opened in a given time.

The unit has been tested and shown to be successful on several other weeds besides bracken and cape tulip. They include Paterson's curse *Echium plantagineum* L., Parramatta grass *Sporobolus indicus* (L.) R. Br. var. *capensis* Engl., onion weed *Asphodelus fistulosus* L., South African or branched onion weed *Trachyandra divaricata* (Jacq.) Kunth. and carnation weed *Euphorbia terracina* L. It has also been used to apply glyphosate and paraquat to control the seed set of annual grasses such as barley grass *Hordeum leporinum*, Link, brome grass *Bromus* spp., silver grass *Vulpia* spp. and annual ryegrass *Lolium rigidum* Gaudin, in preparation for a cereal crop the following season.

The improvement in the construction of units to wipe herbicides onto weeds and the wide variation in types of herbicide wiping equipment (1) should give much greater control and flexibility of operation.

Price (5), working in the semi arid tropical areas of Australia, suggested that this technique should be evaluated to control regeneration of perennial weeds at the beginning of a growing season and annual weeds at the end of the growing season, using multiple applications when the weeds appear above the canopy of the desired species. The potential for use in pastures, row cropping, plantations and along roadsides should see an increased interest in the use of this technology.

Apart from the chemicals mentioned in the tests carried out in Western Australia, there has been testing of products such as imazapyr, glufosinate, sulfometuron, dicamba, picloram, hexazinone, clopyralid, triclopyr and fluroxypyr. Wiping herbicides eliminates the risk of spray drift away from the site of application, giving greater operator, public and environmental safety. Effective treatment of tall weeds can be achieved in or adjacent to sensitive crops, pasture or public amenity areas.

Table 1. Comparison of blanket wiper and boom-spray to apply chemicals for control of bracken

| | Rate a.i./ha | Frond count/m | % Reduction bracken | % Clover damage |
|---|---|---|---|---|
| **Booms-pray** | | | | |
| Glyphosate (450) | 1.35 kg | 12 | 52 | 55 |
| Metsulfuron | 18 g | 6 | 95 | 65 |
| Glyphosate (450) + metsulfuron | 0.9 kg + 18 g | 5 | 98 | 50 |
| **Blanket-wiper** | | | | |
| Glyphosate (450) + metsulfuron single pass | 2.7 kg + 18 g | 6 | 93 | 0 |
| Glyphosate (450) + metsulfuron double pass | 5.4 kg + 36 g | 4 | 93 | 0 |
| Untreated | | 16 | 0 | 0 |

All treatments applied with Pulse Penetrant® at 0.2%.

Table 2. Control one year after treatment of one and two leaf cape tulip using a blanket wiper to apply the chemicals

| Treatment | | Rate a.i./ha | %Reduction single leaf | %Reduction two leaf |
|---|---|---|---|---|
| 1. | Metsulfuron | 0.3 g | 88 bcd | 52 b |
| 2. | Metsulfuron | 3.0 g | 97 d | 94 cd |
| 3. | Metsulfuron + glyphosate (450) | 0.3 g + 0.113 kg | 84 bc | 68 bc |
| 4. | Metsulfuron + glyphosate (450) | 3.0 g + 0.113 kg | 89 cd | 90 cd |
| 5. | Metsulfuron + glyphosate (450) | 0.3 g + 0.225 kg | 85 bc | 84 cd |
| 6. | Metsulfuron + glyphosate (450) | 3.0 g + 0.225 kg | 89 cd | 94 cd |
| 7. | Metsulfuron + glyphosate (450) | 0.3 g + 0.45 kg | 87 bcd | 67 bc |
| 8. | Metsulfuron + glyphosate (450) | 3.0 g + 0.45 kg | 88 cd | 93 cd |
| 9. | Untreated | | 0 a | 0 a |

* Values followed by the same letter do not differ significantly (P = 0.05).

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# HERBICIDAL EFFECT IN THE DEVELOPMENT OF PARTHENOCARPY IN OIL PALM

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*Summary*: The herbicidal effect of sulfosate on the production of parthenocarpic fruits was evaluated in two trials on two to three-year old oil palms. The first trial compared two formulations of sulfosate, dicamba and picloram, and the second study was conducted to reconfirm the results. Results indicate that sulfosate applied at 0.72 and 1.44 kg salt/ha (equivalent to 1.5 and 3.0 L/ha) were safe to oil palm fruits where no development of parthenocarpic fruits was observed. There is evidence to indicate that both picloram and dicamba caused significant amount of parthenocarpic fruits, with picloram being more severe than dicamba. Results of these trials and field observations indicate that sulfosate can be used safely on young two to three-year old palms.

*Keywords*: sulfosate, oil palm, parthenocarpy

## INTRODUCTION

Weed control in oil palm plantations using herbicides is one of the most important agriculture input in oil palm production. However, selection of the right herbicide for control of weeds is important, in particular during the young stages of oil palm development. This is because certain herbicides can induce parthenocarpic fruit development (2, 6). The development of parthenocarpic fruit is undesirable because it is smaller and lighter than the normal fruit, resulting in substantial reduction in total oil yield.

Sulfosate (Touchdown®), a non-selective systemic herbicide was introduced for the control of a wide range of weed species in oil palm and rubber plantings. Its field performance in weed control has been shown to be consistently better than glyphosate (1, 3, 4, 5). This paper describes studies conducted to examine the possible effects of sulfosate on development of parthenocarpic fruits in oil palm.

## MATERIALS AND METHODS

Two experiments were conducted on two to three-year-old oil palm plantings. In the first trial, two formulations of sulfosate (Touchdown® containing 480 g salt/L sulfosate, and the low strength formulation of sulfosate containing 160 g salt/L) at application rates of 0.72 and 1.44 kg salt/ha were compared with dicamba at 0.28 kg ae/ha and picloram at 0.142 kg ae/ha. The second trial was carried out with sulfosate compared directly with the untreated control to reconfirm the observations obtained from the first trial.

The two experiments were conducted in two oil palm estates in Melaka. Trials were conducted in randomised complete block design with four replicates with plot size ranging from 4 to 6 palms. Application of herbicides was carried out using a knapsack sprayer equipped with a 5/64" fan nozzle delivering a spray volume of 450 L/ha to palm circles of about 2 m radius. A spray solution of about 10 ml equivalent to field strength solution in 450 L/ha was deliberately targeted at the inflorescence of selected fruit bunches to simulate spray drift. Female inflorescence before reaching receptive and at the receptive stages were marked for the spray. A total of two sprays were applied at eight weeks interval in Trial 1 whereas one single spray was applied in Trial 2.

The sprayed female inflorescence were observed for parthenocarpy development. In trial 1, observations were carried out at 8 and 16 weeks after the first application on newly developed fruit bunches as well as the total number of bunches present on the palms. Assessments were made at 4 and 8 weeks after treatment in Trial 2.

## RESULTS AND DISCUSSION

Results in Trial 1 showed that both the sulfosate formulations at 0.72 and 1.44 kg salt/ha, when directed onto female inflorescence did not produce any parthenocarpic fruits with two sequential applications at 8 week interval (Table 1). Picloram and dicamba treatments induced 100% parthenocarpic fruits. Similar observations were reported by Khairudin & Teoh (2) and Wan (7).

Overall assessment of fruit bunches at 16 weeks after two rounds of spraying indicate that picloram caused a significant 74% induction of parthenocarpic fruits, followed by 39% by dicamba (Table 2). Both the sulfosate formulations tested did not induce any abnormal fruits.

Simulated spray-drift of sulfosate onto female inflorescence did not produce any parthenocarpic fruits (Table 3). Fruit development in these treatments were normal as found on palms in the untreated control plots. The result of the second trial further confirmed these findings. These observations confirm that sulfosate is safe to be applied for the control of weeds in oil palm plantings. Although it is normal for young palms to produce parthenocarpic fruits naturally in the initial fruit bearing stage, no parthenocarpic fruits were observed in both trials.

Table 3. Bunch counts of developed fruits after a single spray of herbicides (Trial No. 2)

| Treatment | Rate/ha | No. of palms treated | No. of female inflorescence at receptive stage | No. of female inflorenscence just after receptive stage | No. of parthenocarpic bunches at 4 WAA | No. of parthenocarpic bunches at 8 WAA* |
|---|---|---|---|---|---|---|
| Sulfosate | 1.5 L | 16 | 4 | 10 | 0 | 0 |
| | 3.0 L | 16 | 3 | 9 | 0 | 0 |
| Control | | 16 | 4 | 7 | 0 | |

*Weeks after application

## CONCLUSION

Results of both trials showed that sulfosate applied directly onto the female inflorescence at 0.72 and 1.44 kg salt/ha, as simulated spray drift, did not induce development of parthenocarpic fruits in oil palms. Abnormal development of parthenocarpy in oil palms is undesirable. Loss in yield due to picloram effect can be as high as 86.5% (2). It can be concluded that sulfosate is safe for circle spraying in young oil palms with no risk of inducing parthenoearpic fruits.

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Table 1. Bunch counts of developed fruits at 8 and 16 weeks after two sequential application of herbicides

| Treatment | Rate/ha | No. of palms treated | Assessment at 8 weeks after application | | | Assessment at 16 weeks after application | | |
|---|---|---|---|---|---|---|---|---|
| | | | No. of new bunches observed | No. of fully parthenocarpic fruits# | No. of partial parthenocarpic fruits## | No. of new bunches observed | No. of fully parthenocarpic fruits# | No. of partial parthenocarpic fruits## |
| Dicamba | 0.7 l | 24 | 25 | 21 | 4 | 15 | 13 | 2 |
| Picloram | 0.5 l | 24 | 27 | 22 | 5 | 18 | 14 | 4 |
| Sulfosate* | 1.5 l | 24 | 19 | 0 | 0 | 16 | 0 | 0 |
| | 3.0 l | 24 | 23 | 0 | 0 | 19 | 0 | 0 |
| Sulfosate** | 1.5 l | 24 | 25 | 0 | 0 | 20 | 0 | 0 |
| | 3.0 l | 24 | 26 | 0 | 0 | 17 | 0 | 0 |
| Control | | 24 | .27 | 0 | 0 | 13 | 0 | 0 |

* Touchdown® formulation containing 480 g salt/l ** formulation containing 160 g salt sulfosate/l
# Fully parthenocarpic - with more than 50% of the fruits with closed stigma
## Partially parthenocarpic - up to 50% of the fruits in the bunch have closed stigma

Table 2. Total fruit bunches afftected by 2 rounds of herbicide sprayings at 16 weeks after application

| Treatment | Rate/ha | No. of palms treated | Total no. of fruit bunches observed | No. of parthenocarpic fruits | % of parthenocarpic fruits |
|---|---|---|---|---|---|
| Dicamba | 0.7 l | 24 | 164 | 64 | 39 |
| Picloram | 0.5 l | 24 | 187 | 138 | 74 |
| Sulf4osate* | 1.5 l | 24 | 168 | 0 | 0 |
| | 3.0 l | 24 | 156 | 0 | 0 |
| Sulfosate** | 1.5 l | 24 | 183 | 0 | 0 |
| | 3.0 l | 24 | 199 | 0 | 0 |
| Control | | 24 | 161 | 0 | 0 |

* Touchdown® formulation containing 480 g salt/l ** formulation containing 160 g salt of sulfosate/l

# EVALUATION OF CARFENTRAZONE-ETHYL IN COMBINATION WITH GLYPHOSATE AND GLUFOSINATE FOR WEED CONTROL IN ORCHARDS

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*Summary*: Effect of a new post-emergence herbicide carfentrazone-ethyl for controlling weeds in pear orchards was examined and compared with that of glyphosate and glufosinate. Carfentrazone-ethyl alone effectively controlled dicot weeds in orchards, but not monocot weeds. Especially, sedges were not adequately controlled by carfentrazone-ethyl alone at all application rates examined. Glyphosate or glufosinate was more effective to control monocot weeds than carfentrazone-ethyl, whereas carfentrazone-ethyl exhibited greater effect on dicot weeds than glyphosate or glufosinate. Carfentrazone-ethyl mixed with glyphosate exhibited a higher degree of weed control, especially on *Echinochloa crus-galli*, as compared to the herbicide mixture of carfentrazone-ethyl with glufosinate. However, no phytotocixity of the herbicides to pear trees was observed. Carfentrazone-ethyl was found to be useful to reduce application rates and accelerate the effect of glyphosate or glufosinate. Thus, carfentrazone-ethyl in combination with glyphosate can be used to successfully control most weeds in orchards.

*Keywords*: carfentrazone-ethyl, glyphosate, glufosinate, orchard, herbicide mixture.

## INTRODUCTION

In Korea, several herbicides such as paraquat, glyphosate, and glufosinate have routinely been used as post-emergence herbicides for controlling weeds in orchards (1, 3). However, multiple applications are often needed to maintain acceptable weed control in orchards, since a single application of the individual herbicides does not provide complete weed control (1-3). Furthermore, a few weed species, which are difficult to control with the above herbicides, continue to be a problem (2).

Carfentrazone-ethyl (F8426), a new post-emergence herbicide discovered (6) and being developed by FMC Corporation, is a low dosage, non-residual, contact herbicide that effectively controls many important weeds in cereal culture (9). Carfentrazone-ethyl can be used as an effective post-emergence herbicide to control weeds in orchards. Since carfentrazone-ethyl is a rapid acting herbicide (9), the new herbicide might substitute paraquat the use of which is now banned in some countries and becoming increasingly limited in others due to its high toxicity to mammals.

In the present study, we examined the effect of carfentrazone-ethyl compared to glyphosate and glufosinate for control of many problem weeds in orchards. We also examined the effect of mixtures of carfentrazone-ethyl plus glyphosate or glufosinate to determine whether herbicide mixtures would provide better and longer period of weed control than the herbicides applied alone, and whether lower herbicide rates could be used in the herbicide mixtures.

## MATERIALS AND METHODS

Field experiments were conducted in orchards at three different locations in Korea. Ten-to fifteen-year-old pear trees (*Pyrus pyrifolia* cv. Shinko) were growing in the orchards. Each experimental plot was 4x4 m and contained at least one pear tree to examine if herbicides caused any phytotoxicity to the trees. Just prior to herbicide treatments, weed distribution in the orchards was examined with respect to emergence frequency of individual weed species and coverage rate.

Herbicides tested were applied in mid June when weeds had reached an average height of 15-20 cm. Carfentrazone-ethyl was applied at various rates alone or in combination with glyphosate or glufosinate at half of the recommended rate using a laboratory belt sprayer delivering 100 L/ha spray volume. For comparison, glyphosate or glufosinate at the recommended rate was also applied to the orchards. Emulsifiable concentrate of carfentrazone-ethyl (24% ai) was used, whereas soluble concentrates of glyphosate (41% ai) and glufosinate ammonium (18% ai) were used. The rates for all treatments are given in Table 1. After herbicide application, visual herbicide efficacy ratings were made at various time intervals using a 0~100 scale, where 0 represents no control and 100 being equivalent to complete control. On this scale, acceptable weed control is a rating of greater than 80%. At 30 days after application (DAA), fresh weights of each surviving weed species were measured to calculate weed control value. The experimental design was a randomized complete block with three replications.

Table 1. Rates for herbicide treatments used in the study.

| Treatment | Herbicide | Rate (g ai/ha) |
|---|---|---|
| 1 | Untreated | - |
| 2 | Carfentrazone-ethyl | 12.5 |
| 3 | Carfentrazone-ethyl | 25 |
| 4 | Carfentrazone-ethyl | 50 |
| 5 | Glyphosate | 1230 |
| 6 | Glufosinate | 540 |
| 7 | Carfentrazone-ethyl + Glyphosate | 12.5 + 615 |
| 8 | Carfentrazone-ethyl + Glyphosate | 25 + 615 |
| 9 | Carfentrazone-ethyl + Glyphosate | 50 + 615 |
| 10 | Carfentrazone-ethyl + Glufosinate | 12.5 + 270 |
| 11 | Carfentrazone-ethyl + Glufosinate | 25 + 270 |
| 12 | Garfentrazone-ethyl + Glufosinate | 50 + 270 |

## RESULTS AND DISCUSSION

The experimental orchards in mid June were infested mainly by dicots *Amaranthus ascendens*, *Artemisia princeps*, *Chenopodium album*, *Polygonum hydropiper*, *Erigeron canadensis*, *Commelina cummunis*, and *Calystegia japonica*, monocots *Echinochloa crus-galli*, *Digitaria sangunalis*, *Setaria viridis*, and several sedges (data not shown). Dicots *Acalypha australis*, *Stellaria media*, *Trifolium repens*, *Sonchus oleraceus*, *Humulus japonicus*, *Plantago asiatica*, and *Galium spurium* were also found in the orchards.

Carfentrazone-ethyl alone effectively controlled most dicot weeds in the orchards, but not monocot weeds (Table 2, Fig. 1). This result might be due to the fact that carfentrazone-ethyl is a contact herbicide (9) and thus does not kill the protected growing points of monocot weeds. Glyphosate or glufosinate was more effective for control of monocot weeds than carfentrazone-ethyl, whereas carfentrazone-ethyl at 50 g ai/ha exhibited greater effect on dicot weeds than glyphosate or glufosinate (Table 2, Fig. 1). Glyphosate or glufosinate alone completely controlled sedges in the orchards. The sedges were not adequately controlled by carfentrazone-ethyl alone at all application rates examined (Table 2). Effect of carfentrazone-ethyl in controlling dicot weeds was found to be much faster than that of glyphosate or glufosinate (Fig. 1). Acceptable weed control of 80% on dicot weeds was achieved at 8 DAA by carfentrazone-ethyl at 50 g ai/ha, but glufosinate and glyphosate at the recommended rates provided acceptable weed control at 11 and 15 DAA, respectively (Fig. 1). Carfentrazone-ethyl is a fast acting herbicide which is known to exert its herbicidal effect by causing rapid membrane disruption (9). Carfentrazone-ethyl is also known to have the same mechansim of action as diphenyl ethers and sulfentrazone (F6285) in which membrane disruption is due to the inhibition of protoporphyrinogen oxidase, the last common enzyme in the biosynthesis of both heme and chlorophylls, leading to the accumulation of abnormally high level of phytotoxic intermediate, protoporphyrin (4, 5, 7, 9).

Table 2. Effect of carfentrazone-ethyl alone and in combination with glyphosate or glufosinate on the biomass of major weed species in orchards.

| Treatment[1] | Weed species[2] | | | | | | | Dicots | Weed species[2] | | | | Monocots |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aa | Ap | Ca | Ph | Ec | Cc | Cj | | Ecg | Ds | Sv | Sedges | |
| | biomass (g/m²)[3] | | | | | | | (%)[4] | biomass (g/m²)[3] | | | | (%)[4] |
| 1 | 82.3 | 277 | 98.5 | 62.5 | 127 | 29.3 | 63.8 | 0 | 235 | 93.7 | 86.5 | 69.8 | 0 |
| 2 | 17.6 | 72 | 21.3 | 14.6 | 33.6 | 14.3 | 26.6 | 73 | 177 | 106 | 56.3 | 46.3 | 18 |
| 3 | 0 | 58.6 | 0 | 0 | 11.3 | 0 | 0 | 91 | 184 | 72 | 48.6 | 40.6 | 27 |
| 4 | 0 | 13.3 | 0 | 0 | 0 | 0 | 0 | 98 | 135 | 55.6 | 35.6 | 21.6 | 46 |
| 5 | 0 | 13 | 0 | 0 | 9 | 0 | 0 | 97 | 29.6 | 10.3 | 14 | 0 | 87 |
| 6 | 0 | 0 | 0 | 0 | 9.3 | 0 | 0 | 99 | 42.3 | 16 | 18.6 | 0 | 82 |
| 7 | 0 | 21.6 | 0 | 0 | 9.6 | 0 | 0 | 96 | 70.3 | 42 | 25.3 | 0 | 67 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 31 | 22.3 | 12.3 | 0 | 84 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 22.6 | 15.6 | 8.6 | 0 | 89 |
| 10 | 12.6 | 28.3 | 0 | 10.3 | 14.6 | 3.3 | 14 | 89 | 115 | 49 | 33 | 0 | 53 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 62 | 30.3 | 17.6 | 0 | 74 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 45.3 | 21 | 12.6 | 0 | 81 |

[1] Treatment numbers are the same as in Table 1.

[2] Major weed species examined were Aa, *Amaranthus ascendens*; Ap, *Artemisia princeps*; Ca, *Chenopodium album*; Ph, *Polygonum hydropiper*; Ec, *Erigeron canadensis*; Cc, *Commelina cummunis*; Cj, *Calystegia japonica*; Ecg, *Echinochloa crus-galli*; Ds, *Digitaria sangunalis*; Sv, *Setaria viridis*; and sedges.

[3] At 30 DAA, fresh weights of each surviving weed species were measured.

[4] Weed control value compared to untreated control.

Carfentrazone-ethyl is a low dosage herbicide at field application rates of between 4.5 and 35 g ai/ha (9), and the recommended rates of glyphosate and glufosinate are at least 35- and 15-fold higher than that of carfentrazone-ethyl, respectively. If the herbicide mixtures of carfentrazone-ethyl plus glyphosate or glufosinate at half the recommended rate can control the weeds in the orchards as effectively as glyphosate or glufosinate alone applied at their full recommended rates, carfentrazone-ethyl might be useful to reduce the application rates of glyphosate or glufosinate. Carfentrazone-ethyl mixed with glyphosate or glufosinate at half the recommended rate controlled monocot weeds as well as dicot weeds more effectively than the herbicides applied alone (Table 2). Carfentrazone-ethyl mixed with glyphosate gave greater control of weeds, especially *Echinochloa crus-galli*, compared to the mixture of carfentrazone-ethyl with glufosinate (Table 2). Along with the fact that carfentrazone-ethyl could be used to reduce the application rates of glyphosate or glufosinate, carfentrazone-ethyl was also found to accelerate the weed control effect of glyphosate or glufosinate. Acceptable weed control of 80% on dicot and monocot weeds was achieved at 4 and 8 DAA, respectively, by mixtures of carfentrazone-ethyl at 50 g ai/ha plus glyphosate or glufosinate at half the recommended rate (Fig. 1). For example, the acceptable weed control on dicot and monocot weeds was attained 11 and 5 days earlier, respectively, by the mixture of carfentrazone-ethyl plus glyphosate than glyphosate applied alone. No phytotocixity to pear trees was observed (data not shown).

Weed control is often better and longer with herbicide mixtures than with a single herbicide (1, 8). By using herbicide mixtures, the build-up of resistant weed species and the development of herbicide resistant weed biotypes could also be prevented or delayed. In addition, application cost could be considerably reduced. Based on our results, it can be concluded that carfentrazone-ethyl in combination with glyphosate can be used to successfully control the most important weeds in orchards.

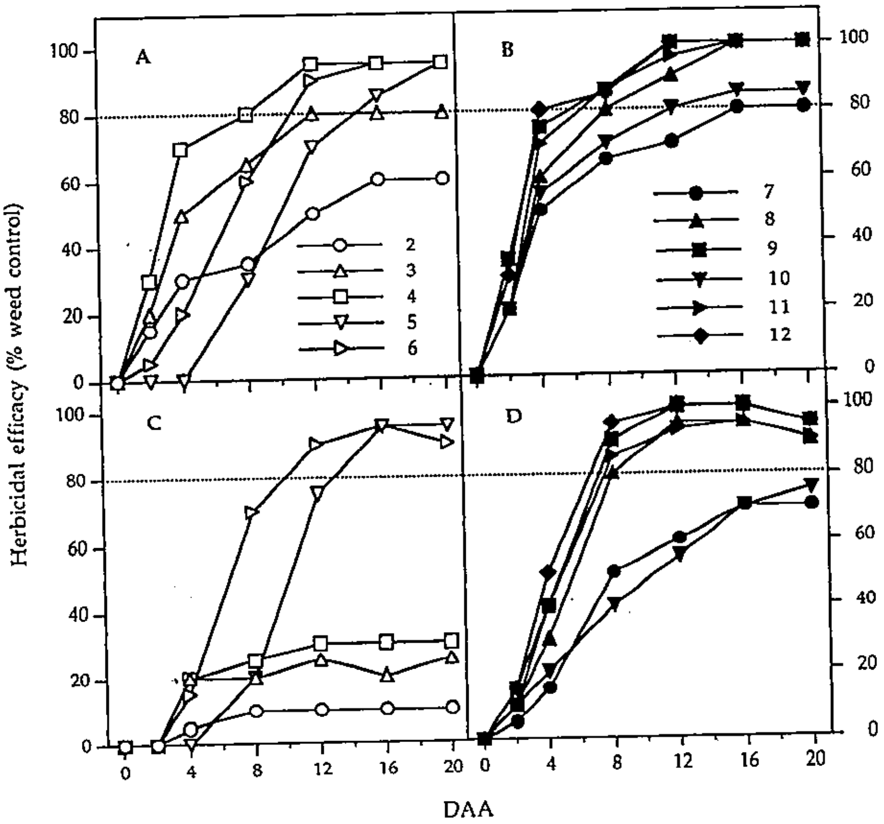


Fig. 1. Effect of carfentrazone-ethyl alone and in combination with glyphosate or glufosinate for the control of dicot weeds (A, B) and monocot weeds (C, D) in orchards. Treatment numbers are the same as in Table 1. A rating of 0 represents no weed control and 100 indicates complete control. Effects of the individual herbicides are represented by unfilled symbols, whereas effects of the herbicide mixtures are represented by filled symbols.

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# GROWTH CHARACTERISTICS, EMERGENCE PATTERNS AND CONTROL OF TORPEDOGRASS (*PANICUM REPENS* L. ) IN SUGARCANE

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*Summary*: Growth characteristics, emergence patterns and their relation to the control were studied to locate vulnerable points in the life cycle of torpedograss (*Panicum repens* L. ) for developing effective control measures in sugarcane. Rhizome formation of torpedograss was initiated at 50 days after planting (DAP), and primary and secondary branch formation of rhizomes were initiated at 70 and 130 DAP, respectively. Torpedograss rhizome buds and bulbs emerged at higher rate during 5-30 DAP from soil cover depth (SCD) of 20 cm. Less number of emergence was recorded during 30-90 DAP from SCD of 50 cm. Weeding at 45 DAP showed weed free environment in both plant and ratoon sugarcane and resulted in significant higher yields Asulam {Methyl N-(4-aminobenzenesulfonyl)- carbamate} applied 3 times at 3.0 kg ai/ha with an interval of 40 days starting at 40 DAP resulted in successful control.of torpedograss. Control methods were more effective when applied at beginning or before rhizome formation. The vulnerable point to control torpedograss was within 45 days of emergence.

*Keywords*: torpedograss growth, critical control period

## INTRODUCTION

Weed's life span, growing season and methods of propagation help to find out the critical period of infestation that ultimately help efficient control or eradication (1). Studies on emergence behavior and emergence patterns of seeds, propagules and other aspects of weed biology are most vital aspects to gain an insight into the mechanism of specialization and distribution of species, and are necessary to arrest the weed growth potential and to locate vulnerable points in the life cycle when control can be successfully carried out (5, 7, 11). Noguchi *et al.* reported that knowledge regarding competition between crop and weed, particularly the suppression effect of weed on the growth and development of the crop and vice versa is essential for developing an ideal model for weed control (9). Torpedograss (*Panicum repens* L.) is a troublesome perennial weed in 19 field crops in tropical and subtropical areas (2, 3, 8, 10). The yield reduction of sugarcane caused by torpedograss was recorded up to 80%. It is a serious weed in Okinawa infesting various crop fields, orchards, golf courses and fallow lands (3). Systematic studies on control of torpedograss in relation to its growth characteristics and emergence patterns in sugarcane were not available. Present studies were conducted to locate vulnerable points in the life cycle of torpedograss for effective control measures in sugarcane.

## MATERIALS AND METHODS

*Growth Characteristics:* Field experiment was carried out in 1993-1994 on reddish soil at the experimental farm in the University of Ryukyus, Japan. The soil contained 0.89% C, 0.11% N, 134 mg P/100g soil , and exchangeable K, Ca, Mg and Na were 0.17, 10.8, 1.35 and 0.31 me/100g soil, respectively. Soil pH was 5.25-6.74. Five single-bud rhizome cuttings of torpedograss were planted at the center of each plot (3x3 m). One plant/plot which emerged first was allowed to grow and the rest were removed after emergence. Other weed species were removed by hand weeding. Fertilizer was not applied in the experiment. Water was applied when required. Soil temperature was recorded everyday. Data were recorded at each sampling date on five random plants at intervals of 20 days starting at 30 days after planting (DAP). Growth parameters of torpedograss were recorded at each sampling date (Table 1).

*Emergence Pattern:* A pot experiment was conducted on reddish soil in 1994 in the glasshouse. Rhizome, cuttings with one, two, four, eight and above ten buds and complete plants (rhizome with shoot) and bulbs of torpedograss were planted in plastic pipes (25 cm diameter x 80 cm height) at soil depths of 1, 2, 3, 5, 10, 15, 20, 30, 40 and 50 cm in three replications. Total number of buds and bulbs investigated were 4371. The range of soil temperature was between 26 and 32°c. The plants were watered regularly to ensure optimum soil moisture condition. Data on torpedograss emergence were recorded at 5, 10, 15, 20, 30, 60 and 90 DAP. Roots with rhizomes were washed at harvest to identify tillers. Number of tillers were counted and actual emergence over each time interval obtained. Data for each replication were converted to percentage and were analyzed statistically by Duncan's multiple range test.

*Manual and Mechanical control:* Field experiments were conducted in 1994-1995 and 1995-1996 cropping season on reddish soil. The treatments with three replications were T1(0) Pure stand weed; T2(0), Pure stand sugarcane;T3(45): weeding at 45 days after planting (DAP); T4(60), weeding at 60 DAP, T5(90), weeding at 90 DAP, T6(120), weeding at 120th DAP and T7(NW), no weeding. One-bud rhizome cuttings were planted for T1(0) in trenches in 2 rows maintaining 15 cm distance between cuttings in a quadrat fashion. Single-bud sugarcane cuttings (cv. NCo 310) were planted in trenches maintaining 30 cm apart. For weed-sugarcane mixed plots { T3(45), T4(60), T5(90), T6(120) and T7(NW) } four rhizome cuttings were planted around each sugarcane cutting maintained 15 cm distance in a quadrat fashion. At 60 days after harvest of plant cane, interrows were ploughed for weed management and earthing up the base of the ratoon cane. Other weed species were removed when found by regular hand weeding. Necessary and recommended agronomic practices were carried out as required. Data for sugarcane were recorded from the middle two rows. Weed data were recorded from the middle inter-row. Data were analyzed statistically by Duncan's multiple range test.

*Chemical control:* The field experiment was conducted in 1996-1997, in fields heavily infested with torpedograss. Sugarcane ( cv. NCo 310) was planted and recommended agronomic practices were done as required. Asulam {Methyl N-(4-aminobenzenesulfonyl)-carbamate} was applied at 3 kg ai/ha for torpedograss control in sugarcane. Four treatments with three replications were T1, asulam applied 3 times with an interval of 40 days starting at 40 DAP; T2, asulam applied 3 times with an interval of 70 days starting at 70 DAP; T3, asulam applied 3 times with an interval of 100 days starting at 100 DAP and T4, untreated check. The plot size was 10.5x3m. Data on weed density and weed dry weight were recorded per $m^2$ basis at chemical application and final harvest. Data were recorded from 3 different places in each replication and the mean calculated. Data on sugarcane injury caused by asulam was not recorded in this experiment because several experiments had shown no injury to sugarcane by asulam at 3 kg ai/ha, and sugarcane was only injured by asulam when applied at planting and in the early growth stage under continuous rainfall.

## RESULTS AND DISCUSSION

*Growth characteristics*: Shoot production from main rhizomes and their branches were lowest during 30-50 DAP. Subsequently, they increased rapidly upto 190 DAP (Table 1). The main rhizome was not found at 30 DAP. Rhizome number rapidly increased from 50 DAP to 110 DAP. Thereafter, rhizome production slowed down. However, a slight increase in rhizome number was observed up to 190 DAP. Rhizome elongation was initially slow and it was only 7 cm at 50 DAP and 63 cm at 70 DAP. After 50 DAP, it began elongating rapidly and reached a length of 192 cm at 190 DAP. Rhizomes penetrated the soil upto 42cm depth. Primary and secondary branch formation from main rhizomes were initiated at 70 and 130 DAP, respectively. From 70 DAP to 130 DAP, slow primary branch formation was observed and later it increased sharply with time. Secondary branch formation subsequently increased with the increased number of primary branches. Rhizome weight increased with increase in rhizome branches and elongation.

Table 1. Changes in torpedograss growth parameters with time { days after planting (DAP)} [a]

| | Growth parameters | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | St. length | St. no. | Rhi. no. | Rhi. length | Pri. bra. | Sec. Bra. | Rhi. Pe. | St. dry wt. | Rhi. dry wt. |
| DAP | Cm | /plant | /plant | cm | no./plant | no./plant | cm | g/plant | g/plant |
| 30 | 18 | 0.4 | 0 | 0 | 0 | 0 | - | 0.2 | 0.7 |
| 50 | 25 | 2.4 | 1.2 | 7 | 0 | 0 | - | 0.6 | 2.7 |
| 70 | 70 | 7.0 | 1.8 | 63 | 4.0 | 0 | - | 3.1 | 1.8 |
| 90 | 64 | 11.8 | 2.2 | 72 | 5.4 | 0 | 25 | 4.7 | 5.2 |
| 110 | 83 | 13.6 | 4.6 | 88 | 4.4 | 0 | 29 | 5.6 | 10.5 |
| 130 | 79 | 21.4 | 4.5 | 116 | 5.3 | 2.8 | 30 | 18.6 | 22.4 |
| 150 | 81 | 29.8 | 5.3 | 152 | 13.0 | 6.5 | 26 | 27.0 | 36.0 |
| 170 | 74 | 37.3 | 5.5 | 169 | 16.3 | 5.5 | 32 | 22.3 | 33.0 |
| 190 | 80 | 47.8 | 5.3 | 192 | 19.8 | 8.8 | 42 | 46.0 | 70.9 |

Note: [a] Modified from Hossain et al. (4), St=Shoot, no.=number, Rhi.=Rhizome, Pri.=Primary, Sec.= Secondary, bra.=branch, Pe.=Penetration in soil, wt.=weight, "-" data not recorded

*Emergence pattern:* Soil cover depth (SCD) of 1-3 and 5-20 cm recorded higher rate of emergence within 5-20 and 10-30 DAP, respectively. Overall, higher rates were recorded within 5-30 DAP from the SCD up to 20 cm compare to 30-90 DAP from the maximum SCD of 50 cm (Table 2).

*Manual and mechanical control:* Shoots increased geometrically (Table 3) with delay in weeding because of higher tillering and rapid elongation (5). Tiller production increased with increased production of rhizomes. Torpedograss was not found at harvest in plots where weeding was done at 45th DAP (6, 11). Delay in weeding also recorded higher weed biomass at harvest. Weed was completely removed at 45 DAP but this was difficult at 60 DAP or later. Plots with weeding treatments at 90 DAP or later showed severe re-infestation in both plant and ratoon sugarcane, due to incomplete removal of rhizomes which caused re-infestation. Plots with weeding at 45 DAP in plant cane were torpedograss-free in ratoon cane. Weeding at 60 DAP or later in plant cane had no positive effect on weed control in ratoon cane compared to ratoon of non-weeded sugarcane. Plant cane recorded rhizome weight of 82 g/m$^2$ in T4(60) which resulted in 1,242 g/m$^2$ of weed biomass in ratoon cane. Significantly lower yield of sugarcane was recorded in T5(90) followed by T6(120) and T7(NW). Yield and yield parameters (data not presented) decreased with delay in weeding. Plant cane usually initiated tillering from approximately 45 DAP and the tillers which were formed within 90 DAP usually produced better yield (3). Yield decreased by 0.9-1.5% per day due to delay in weeding during 45-90 DAP (4, 6, 9). Ratoon yield of T2(0) and T3(45) was significantly higher than ratoon yield of longer weed infested sugarcane.

Table 2. Emergence rate (%) of torpedograss at different days after planting (DAP) at different soil cover depth

| DAP | Soil cover depth (cm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | □1 | 2 | □3 | □5 | □10 | □15 | □20 | □30 | □40 | □50 |
| | Emergence rate (%) | | | | | | | | | |
| □0~5 | 0.29b | 0.06b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5~10 | 1.77ab | 1.43b | 1.46ab | 0.17a | 0 | 0 | 0 | 0 | 0 | 0 |
| 10~15 | 3.74a | 3.94a | 2.97a | 1.91a | 1.15b | 0.43b | 0.06a | 0 | 0 | 0 |
| 15~20 | 1.94ab | 1.29b | 1.14ab | 1.83a | 1.60b | 0.71b | 1.03a | 0 | 0 | 0 |
| 20~30 | 0.90b | 0.50b | 0.64ab | 1.21a | 1.94a | 1.34a | 1.16a | 0.69a | 0.37a | 0.34a |
| 30~60 | 0.31b | 0.25b | 0.20b | 0.41a | 0.41b | 0.48b | 0.23a | 0.29a | 0.28a | 0.05a |
| 60~90 | 0.01b | 0.11b | 0.01b | 0 | 0.02b | 0.03b | 0.07a | 0.01a | 0.08a | 0.01a |

Note: Means in each column not followed by the same letter are different at 5% level of significance, as determined by Duncan's Multiple Range Test. Values are means of all rhizome cuttings, whole plants and bulbs.

Table 3. Torpedograss biomass and sugarcane yield in plant and ratoon cane under different weeding regimes in plant sugarcane

| Treatments | Torpedograss biomass | | | | | Sugarcane yield (stalk) | |
|---|---|---|---|---|---|---|---|
| | Plant cane | | | Ratoon cane | | | |
| | At weeding | At harvest | | At harvest | | Plant cane | Ratoon cane |
| | St. dry Wt. g/m$^2$ | Rhi. dry Wt. g/m$^2$ | Total dry Wt. g/m$^2$ | Rhi. dry Wt. g/m$^2$ | Total dry Wt. g/m$^2$ | g/m$^2$ | g/m$^2$ |
| T1(0): Pure W. | | 669a | 2257a | 965a | 3220a | - | - |
| T2(0): Pure S. | | - | - | - | - | 5787a | 8267a |
| T3(45): 45 DAP WG. | 3d | - | - | - | - | 5148ab | 9719a |
| T4(60): 60 DAP WG. | 9c | 82d | 121c | 411c | 1242b | 3993bc | 4977b |
| T5(90): 90 DAP WG. | 50b | 137cd | 250c | 437bc | 1159b | 2952cd | 4048b |
| T6(120): 120 DAP WG. | 113a | 240c | 399c | 577b | 1321b | 2624d | 4825b |
| T7(NW): NO WG. | + | 403b | 570b | 535bc | 1840b | 2347d | 4116b |

Note: W.=Weed, S.=Sugarcane, WG.=Weeding, St.=Shoot, Rhi.= Rhizome, wt.=weight, Means in each column not followed by the same letter are different at 5% level of significance, as determined by Duncan's Multiple Range Test. "-" and "+ "indicate absent and weeding was not done, respectively.

*Chemical control:* Torpedograss was controlled successfully when 3 kg ai/ha asulam was applied 3 times at an interval of 40 days starting at 40 DAP (Table 4). Torpedograss had no opportunity to produce rhizomes by 40 days after emergence. Herbicide applied at 40th DAP (1st application) resulted in few shoots emerging from rhizome buds and bulbs left in the soil. These shoots were killed by 2nd application of herbicide. Flushes from remaining rhizome buds and bulbs were killed by the 3rd application of herbicide. Thus rhizome buds and bulbs in soil were reduced and the field was almost weed-free at harvest. On the other hand asulam applied 3 times with an interval of 70 days or more starting at 70th DAP or later resulted in severe re-infestation. This delayed treatment with a longer spray interval did not effectively control the rhizomes.

Table 4. Total number of torpedograss shoots and total shoot dry weight during the cropping season under different herbicide application regimes.

| Herbicide application | | Numbers of shoot/m$^2$ | Dry weight of shoot g/m$^2$ |
|---|---|---|---|
| T1: Applied at | 40 DAP+80 DAP+12 DAP | 70 (44+13+9+4*) | 32 (17+7+5+3*) |
| T2: Applied at | 7 DAP+14 DAP+21o DAP | 162 (76+31+28+27*) | 211 (105+48+41+17*) |
| T3: Applied at | 100 DAP+200 DAP+300 DAP | 1050 (108+221+228+493*) | 1561 (289+447+465+360*) |
| T4: Untreated check | | 847 (847*) | 1119 (1119*) |

Note: Values in parentheses indicate torpedograss shoot numbers and shoot dry weight at 1st, 2nd and 3rd application of herbicide (3 kg ai/ha), respectively, and * indicate the values at harvest.

*General discussion and conclusions:* Above results showed that rhizome formation in torpedograss was initiated at 50th DAP, and primary and secondary rhizome branch formation were initiated at 70 and 130 DAP, respectively. Torpedograss rhizome buds and bulbs emerged in higher numbers during 5-30 DAP from soil depths upto 20 cm. A much lower emergence was recorded during 30-90 DAP from SCD of 50 cm. Weeding at 45 DAP produced an almost weed-free environment in both plant and ratoon sugarcane and resulted in significantly higher yield. Weeding at 90 DAP or later showed severe re-infestation in both plant and ratoon sugarcane. Asulam applied 3 times at 3.0 kg ai/ha with an interval of 40 days beginning at 40 DAP resulted in successful control of torpedograss. Both mechanical and chemical control methods were more effective when applied before or at the beginning of rhizome formation. The experiments indicate that the vulnerable stage to control torpedograss was within 45 days of emergence.

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# PRE-EMERGENCE APPLICATION OF THIAZOPYR IN SUGARCANE

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*Summary:* Weed control efficacy of thiazopyr was investigated in K 88-87 sugarcane grown in 2 districts of Kanchanaburi Province, Thailand, Panomtuan and Tamuang. Thiazopyr at 120, 240, 360 and 480 g ai/ha was applied as pre-emergence alone and in combination with diuron and atrazine in early June 1996. No phytotoxicity to sugarcane plants was observed in both locations. Thiazopyr at 240 g ai/ha or higher rates provided good to excellent weed control until 3 months after application at Tamuang where most weeds were annual grasses. However thiazopyr did not gave good control of weeds at Panomtuan where most of the weeds were annual broadleafs. Thiazopyr in combination with 1,600 g ai/ha atrazine or diuron improved weed control efficiency at Panomtuan. The combination with diuron gave longer period of control than with atrazine.

*Keywords* : thiazopyr, sugarcane, pre-emergence

## INTRODUCTION

Only few herbicides can be used for weed control in sugarcane grown in Thailand. Most of them are more effective against annual broad-leaved weeds. Thiazopyr a pre-emergence herbicide was reported to control grasses in several crops including alfalfa, cotton, peanut, soybean, tree crops, vines and sugarcane (1). The objectives of these experiments were to determine weed control efficacy of thiazopyr and its phytotoxicity to sugarcane when applied alone or in combination with other herbicides.

## MATERIALS AND METHODS

K 88-87 sugarcane was planted at Panomtuan District, Kanchanaburi Province. The soil was silty loam with 0.7% organic matter. The soil pH was 5.6. During herbicide application, air temperature was 28-30°C with relative humidity of 85 to 95 %. The soil temperature was 27-29°C with 9.3% moisture. The same variety of sugarcane was planted at Tamuang District, Kanchanaburi Province. The soil was clay with 2.7% organic matter. The soil pH was 7.1. During herbicide application, air temperature was 29 to 31°C with relative humidity of 70 to 80 %. The soil temperature was 28 to 30°C with 15.5% moistureboth locations were irrigated by furrow system. Fertilizers were applied at recommended rates. Herbicides were applied with a knapsack sprayer in 500 L/ha spray volume. The experiments were designed in a randomized complete block with 4 replications. Spacing between rows was 1.4 m. The plot size was 7.0x6.0 m. Weed control efficacy and phytotoxicity were recorded at 1, 2 and 3 months after application.

## RESULTS AND DISCUSSION

*Panomtuan:* At two months after application the control efficacy of thiazopyr at all rates was reduced to only fair level. However, most annual grasses were controlled by thiazopyr. Broad-leaved weeds *Boerhavia diffusa*, *Ipomoea aquatica*, *I. pes-tigridis*, *Trianthema portulacastrum*, and *Tribulus terrestris* were tolerant to thiazopyr. The combination of thiazopyr with diuron gave btter weed control than thiazopyr alone but not better than diuron alone. The combination of thiazopyr with atrazine gave excellent weed control when compared to atrazin or thiazopyr alone. Thiazopyr alone or in combination with atrazine or diuron did not cause phytotoxicity to sugarcane plants or reduce cane yield (Table 1).

*Tamuang:* At two months after application, thiazopyr at 120 g/ha gave good control but at 240, 360 and 480 g/ha gave excellent control which was at the same level as thiazopyr+diuron, thiazopyr+atrazine, and hexazinone+diuron. Thiazopyr at 240, 360 and 480 g/ha gave almost complete control of grasses but not broadleafs, *Corchorus estuans* and *Eclipta prostata*. Diuron as well as the lowest rate of thiazopyr gave good control of weeds. Thiazopyr at all rates or in combination with atrazine or diuron did not cause phytotoxicity to sugarcane or reduce cane yield (Table 2).

The efficacy of thiazopyr in both locations was different probably due to differences in weed species. At Panomtuan, there were more broadleafs while at Tamuang there were more grasses. Thiazopyr is more effective against grasses than broadleas (1). Hence thiazopyr provided excellent weed control at Tamuang (Table 2). However, the combination of thiazopyr with atrazine or diuron improved control of both broadleafs and grasses at Panomtuan (Table 1). The combination with diuron gave longer period of control than with atrazine.

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Table 1 Visual crop injury and weed control rating at 2 months and cane yield at Panomtuan[1]

| Treatment | Rate g (ai)/ha | Crop injury rating[2] | Overall weed control rating[3] | Control rating on weed species[4] | | | | | | | | | | Cane yield kg/ha |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Broadleaf | | | | | | | Grass | | | |
| | | | | BOEA | COMM | CORC | IPAQ | IPPE | TRIA | TRIB | BRAC | ELEU | LEPT | |
| Thiazopyr | 120 | 0 | 45 | 83 | 80 | 95 | 87 | 65 | 62 | 60 | 100 | 80 | 87 | 91 ab |
| Thiazopyr | 240 | 0 | 59 | 70 | 94 | 96 | 60 | 52 | 79 | 65 | 96 | 91 | 97 | 87 ab |
| Thiazopyr | 360 | 0 | 69 | 92 | 94 | 100 | 47 | 84 | 82 | 80 | 96 | 92 | 100 | 96 ab |
| Thiazopyr | 480 | 0 | 69 | 94 | 96 | 100 | 50 | 80 | 96 | 85 | 99 | 92 | 94 | 97 ab |
| Thiazopyr+diuron | 240+1,600 | 0 | 80 | 100 | 100 | 100 | 75 | 54 | 94 | 91 | 100 | 97 | 99 | 107 a |
| Thiazopyr+atrazie | 240+1,600 | 0 | 91 | 100 | 97 | 100 | 100 | 94 | 100 | 89 | 99 | 93 | 99 | 96 ab |
| Diuron | 2,000 | 0 | 86 | 100 | 100 | 100 | 85 | 100 | 90 | 74 | 100 | 86 | 89 | 104 ab |
| Atrazine | 2,000 | 0 | 49 | 100 | 91 | 75 | 100 | 86 | 81 | 69 | 95 | 24 | 100 | 72 b |
| Hexazinone+diurn | 330+1,170 | 0 | 98 | 70 | 100 | 100 | 100 | 100 | 100 | 99 | 100 | 100 | 99 | 90 ab |
| Atrazine+ametryn | 1,600+1,600 | 0 | 47 | 100 | 100 | 97 | 70 | 100 | 72 | 67 | 67 | 40 | 70 | 77 ab |
| Untreated | | 0 | 0 | 0 | 25 | 25 | 75 | 50 | 0 | 0 | 25 | 0 | 0 | 20 c |
| Weeded | | 0 | 93 | 95 | 99 | 100 | 99 | 96 | 99 | 99 | 95 | 96 | 100 | 86 ab |

[1] Means of 4 replications. [2] Crop injury rating; 0=no injury, 100=plant killed. [3] Overall weed control rating; 0=no control, 100=complete control.

[4] BOER=*Boerhavia diffusa.* COMM=*Commelina benghalensis* CORC=*Corchorus aestuans* IPAQ=*Ipomoea aquatica* IPPE=*Ipomoea pes-tigridis* TRIA=*Trianthema portulacastrum* TRIB=*Tribulus terrestris* BRAC=*Brachiaria reptans* ELEU=*Eleusine verticillata* LEPT=*Leptochloa chinensis*

[5] Means in the same column followed by the same letters are not significantly different at the 5% level by DMRT.

Table 2 Visual crop injury and weed control rating at 2 months and cane yield at Tamuang [1]

| Treatment | Rate g(ai)/ha | Crop injury rating[2] | Overall weed control rating[3] | Control rating on weed species[4]: Broadleaf AMSP | AMVI | CORC | ECLI | PORT | TRIA | Grass BRAC | DIGI | ELEU | LEPT | Cane yield kg/ha |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thiazopyr | 120 | 0 | 79 | 91 | 81 | 74 | 92 | 100 | 100 | 97 | 100 | 100 | 100 | 83 a |
| Thiazopyr | 240 | 0 | 93 | 97 | 96 | 94 | 95 | 100 | 97 | 99 | 100 | 100 | 99 | 103 a |
| Thiazopyr | 360 | 0 | 94 | 100 | 100 | 99 | 99 | 100 | 100 | 99 | 100 | 100 | 100 | 99 a |
| Thiazopyr | 480 | 0 | 99 | 100 | 100 | 98 | 99 | 100 | 100 | 100 | 100 | 100 | 100 | 104 a |
| Thiazopyr+diuron | 240+1,600 | 0 | 98 | 100 | 100 | 99 | 99 | 100 | 100 | 98 | 100 | 99 | 99 | 92 a |
| Thiazopyr+atrazine | 240+1,600 | 0 | 93 | 97 | 97 | 100 | 100 | 100 | 97 | 93 | 100 | 100 | 100 | 98 a |
| Diuron | 2,000 | 0 | 87 | 100 | 96 | 96 | 100 | 100 | 96 | 89 | 95 | 91 | 91 | 88 a |
| Atrazine | 2,000 | 0 | 47 | 100 | 72 | 67 | 97 | 100 | 75 | 15 | 50 | 15 | 15 | 82 a |
| Hexazinone+diuron | 330+1,170 | 0 | 94 | 100 | 100 | 100 | 100 | 95 | 100 | 95 | 100 | 99 | 99 | 94 a |
| Atrazine+ametryn | 1,600+1,600 | 0 | 66 | 100 | 85 | 82 | 100 | 100 | 97 | 35 | 50 | 82 | 35 | 80 a |
| Untreated | | 0 | 0 | 0 | 0 | 0 | 75 | 50 | 62 | 0 | 0 | 0 | 0 | 36 b |
| Weeded | | 0 | 93 | 97 | 96 | 97 | 100 | 100 | 100 | 91 | 100 | 99 | 96 | 94 a |

[1] Means of 4 replications. [2] Crop injury rating; 0=no injury, 100=plant killed. [3] Overall weed control rating ; 0=no control, 100=complete control.

[4] AMSP= *Amaranthus spinosus* AMVI= *Amaranthus viridis* CORC= *Corchorus aestuans* ECLI= *Eclipta prostrata* PORT= *Portulaca oleraceae* TRIA= *Trianthema portulacastrum* BRAC= *Brachiaria reptans* DIGI= *Digitaria ciliaris* ELEU= *Eleusine verticillata* LEPT= *Leptochloa chinensis*

[5] Means in the same column followed by the same letters are not significantly different at the 5% level by DMRT

# EFFECT OF HERBICIDES ON WEEDS OF TEA, *CAMELLIA SINENSIS* L. IN IRAN

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*Summary*: To determine the most effective herbicide and its adequate rate for weed control in tea, an experiment was conducted in tea orchards of Guilan Province in Spring 1994. A completely randomized design with ten treatments, including three herbicides each at three rates and a control, each in 3 replications was performed. Post-emergence herbicides including chlorsulfuron, at 13, 25 and 30 g/ha, 2,4-D amine at 0.8, 1.49 and 2.24 kg/ha, glyphosate, at 2.45, 4.22 and 4.8 kg/ha rates, were treated and compared with the control. The major weeds were, purple nutsedge, curly dock, field bindweed bermudagrass, pigweed species and dallisgrass species. The results showed that all of the herbicides at all applied rates very significantly reduced weed populations in comparison with the control. There was no significant differences among the rates of each herbicide. Glyphosate efficacy was much higher than chlorsulfuron and 2,4-D amine, as all the weeds were controlled.

*Keywords*: tea, glyphosate

## INTRODUCTION

Tea is a beverage crop prized for stimulating effects of the theine it contains. About half of the world's population drink tea regularly (4). It grows well on various soil types in moist environments with adequate rainfall (more than 150 cm annually), and temperatures ranging from 20 to 32°C. Though tea cultivation probably started in China about 4000 years ago, but its cultivation in Iran started in the 1920s around the city of "Lahijan", in Guilan province, north of the country, when an agronomist brought this crop from India (7, 8). The moist and warm environment with adequate rainfall, plus high demand for tea, encouraged the increase in the area under cultivation. More than 36000 hectares of cropland of Guilan and Mazendaran provinces of northern Iran are under tea cultivation.

In tea orchards, weeds not only compete with crop for nutrients, water, space and light, but also interfere with plucking of young buds and leaves and reduce the quality of the product. For instance, the long slender, prostrate stems of field bindweed (*Convolvulus arvensis* L.) climb the tea bushes, twist the buds and leaves and interfere with plucking. It reduces the quality of product by changing the color, taste and smell (1).

Mechanical weed control which is a labour consuming procedure, that increases the aeration of topsoil but damages the feeding root system, is a common practice in Iran. Herbicides cause minimum disturbance of topsoil where feeder roots are concentrated. It The herbicide of choice for weed control in tea orchards depends on the age of the bushes, the density and the weed problem Residual and pre-emergence herbicides such as diuron are phytotoxic to young tea, while pre-emergence application of oxyflourfen (0.36 kg/ha) gave about 90% weed control with no serious crop injury (6). Treatment of glyphosate from above or beneath the tea bushes controlled Japanese spirea (*Spirea japonica* L.) very effectively. Treatment from below further resulted in near-complete suppression of weeds at the end of season with no growth in the following year (3).

Kabir *et al.* (5) have reported that glyphosate (0.96 kg/ha or more), had the highest suppression of weeds when compared with oxyflourfen, 2,4-D, paraquat or estate practice of slashing. Tea yields were highest with glyphosate treatment compared with estate practice (5).

In the months of June and July, when tea production is high and requires intense labour for hand weeding, rice planting is also under way and there are not enough workers to carry out both. This experiment was conducted to determine effective and safe herbicides for tea cultivation.

## MATERIALS AND METHODS

The experiment was conducted on a private tea orchard in the vicinity of Lahijan city in Guilan province, northern Iran, in Spring 1994. Replacement of manual weeding with effective herbicides at adequate rates, and safe for the tea bushes, was the objective of this experiment. The experiment was a completely randomized design with ten treatments, including three herbicides each at three rates (3x3 treatments) and a control (untreated). Each treatment was replicated thrice, using 3x3 m plots, Plots were separated from each other by a 1 m border . Herbicide treatments included chlorsulfuron at 13, 25 and 30 g/ha, 2,4-D amine at 0.8, 1.49 and 2.24 kg/ha, glyphosate at 2.45, 4.22 and 4.8 kg/ha with the addition of an adequate nonionic surfactant. All of the treatments were applied with a compressed-air backpack shielded sprayer delivering 180 L/ha at 207 KPa pressure on May 18. Fertilization, irrigation, pruning and plucking of young buds and leaves were similar in all the treatments.

The experiment was conducted on a 25 year old tea plantation which was rejuvenated by heavy pruning 2 years earlier. The density of tea was 90 to 100 bushes per 100 $m^2$ and the tea canopy covered 70-75% of the land. The soil type in experimental location was Hapludalf (with 4-24% clay, 35-44% sand, 61-33% silt, 4.50.25% organic matter and the pH 3.8-4.7 from topsoil to 50 cm depth).

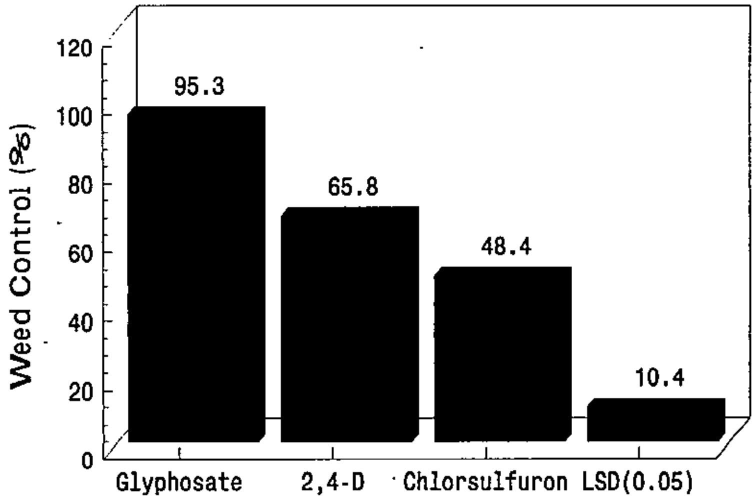
Weed control efficacy of each herbicide was determined within 3 random samples of 1 $m^2$ area in each plot by counting the number of weeds, 20 and 40 days after treatment (DAT). The phytotoxicity of herbicides on tea bushes was visually evaluated once a week for 5 weeks.

## RESULTS AND DISCUSSION

In comparison to the control, all the herbicides reduced weed populations very significantly at all application rates. Glyphosate treatments had the highest percentage of weed suppression (>95%), when compared with control. All the major weeds of tea such as field bindweed (*Convolvulus arvensis* L.), pigweed species (*Amaranthus* spp.), curly dock (*Rumex crispus* L.), common purslane (*Portulaca oleracea* L.) and dallisgrass species (*Paspalum* spp.), and the minor weeds such as sulpher-cinquefoil (*Potentilla recta* L.), crab-grass (*Digitaria sanguinalis* (L.) Scop.), hedge bindweed (*Calystegia* spp.) and Italian ryegrass (*Lolium multiflorum* Lam.) were controlled very well. However, limited re-vegetation by bermudagrass (*Cynodon dactylon* L. Pres.) and purple nutsedge (*Cyperus rotendus* L.) species were observed 40 days after application.

Most of the broad-leaved weeds were controlled by 2,4-D, however, this left the grasses and nutsedge undamaged. Good suppression of field bindweed, pigweed species, and common purslane were observed in 2,4-D treated plots. Chlorsulfuron suppressed bermudagrass, curly dock, and pigweed species very well, but in general its efficacy was lower than glyphosate and 2,4-D. The efficacy of herbicides used indicate the superiority of glyphoste to 2,4-D and 2,4-D to chlorsulfuron, respectively (Figure 1). However, there was no difference among the rates of each herbicide used (Table 1).

None of the herbicides showed major phytotoxic effects on tea, except in one plot where, the drift of chlorsulfuron at 30 g/ha showed minor chlorosis of leaves. The results of this experiment indicate that glyphosate at the lowest rate (2.45 kg/ha) was more effective than 2,4-D and chlorsulfuron for use on tea orchards of Northen Iran.




**Herbicide Efficacy on Tea Weed Control**

Figure 1. Percent weed control of herbicides in tea, using means of counted weeds, 20 and 40 days after application.

Table 1. Comparison among treatments applied for weed control in Tea orchards and the treated rates within each herbicide using *Orthogonal Contrasts* Procedure.

ANOVA with Orthogonal Contrasts

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Among Treatments | 9 | 1398521.87 | 155311.32 | 2365.14** |
| Herbicides vs. control | 1 | 34143.94 | 34143.94 | 5196.83** |
| Glyphosate vs. 2,4-D | 1 | 3028.84 | 3028.84 | 46.10** |
| Glyphosate vs. Chlorsulfuron | 1 | 12683.33 | 12683.33 | 193.05** |
| Chlorsulfuron vs. 2,4-D | 1 | 123534.17 | 123534.17 | 188.04** |
| Glyphosate: Treat.1 vs. 2 | 1 | 0.47 | 0.47 | < 1 ns |
| Glyphosate: Treat.1 vs. 3 | 1 | 1.80 | 1.80 | < 1 ns |
| Glyphosate: Treat.2 vs. 3 | 1 | 0.94 | 0.94 | < 1 ns |
| 2,4-D : Treatment 1 vs 2 | 1 | 1.20 | 1.20 | < 1 ns |
| 2,4-D : Treatment 1 vs 3 | 1 | 0.44 | 0.44 | < 1 ns |
| 2,4-D : Treatment 2 vs 3 | 1 | 0.06 | 0.06 | < 1 ns |
| Chlorsulfuron Treat. 1 vs 2 | 1 | 18 | 18 | < 1 ns |
| Chlorsulfuron Treat. 1 vs 3 | 1 | 43.56 | 43.56 | < 1 ns |
| Chlorsulfuron Treat. 2 vs 3 | 1 | 5.56 | 5.56 | < 1 ns |
| Error | 20 | 1314 | 65.7 | |
| Total | 29 | 1399835.87 | | |

** Highly significant, ns = nonsignificant.

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# WEED MANAGEMENT OPTIONS FOR SMALLHOLDER AGRICULTURE IN THE TROPICS

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*Summary:* The economic environment of tropical smallholders is changing rapidly as demand for their produce increases and diversifies. Farmers respond to market signals by intensifying production, but they are constrained by technical, financial and social factors. Increased herbicide use is an essential component of this intensification process, but must be integrated with mechanical and hand cultivation to provide an appropriate weed management system. Problems and hurdles can be successfully overcome if farmers are able to participate in development programmes where industry and government extension work together. However, it is not yet certain that either of these parties can meet the scale of the challenges which face them.

*Keywords*: tropical weed management, smallholder weed management

## THE ECONOMIC ENVIRONMENT

Whereas the total population in East Asia (including China) is increasing at a rate of 0.9 % per annum, there is an overall decline in the numbers of people involved in agriculture (-0.4 % in the period 2000-2010, Table 1). As shown in this table, there is also a general decrease in the percentage of the economically active population engaged in agriculture, implying fewer farmers are feeding a growing population of urban dwellers. Fewer people are providers of food, but they must increase production to feed those economically active in other fields. In addition to this increased demand, as the urban population becomes wealthier, it diversifies its dietary requirements. People in these countries are eating proportionately less cereals but more meat, vegetables and fruits (7).

Table 1. Numbers of people active in agriculture as a percentage of the total economically active population, and annual growth rates (8).

| | Population economically active in agriculture | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | millions | | | % of total active population | | | Growth rates (%p.a.) | |
| | 1990 | 2000 | 2010 | 1990 | 2000 | 2020 | 1990-2000 | 2000-2010 |
| China (mainland) | 450 | 450 | 424 | 68 | 60 | 52 | 0.0 | -0.6 |
| Indonesia | 35 | 36 | 34 | 49 | 40 | 32 | 0.3 | -0.5 |
| Korea DPR | 3.7 | 3.5 | 3.0 | 34 | 25 | 19 | -0.8 | -1.5 |
| Korea Rep. | 4.6 | 3.5 | 2.4 | 25 | 16 | 10 | -2.7 | -3.7 |
| Malaysia | 2.3 | 2.2 | 2.0 | 32 | 24 | 17 | -0.3 | -0.6 |
| Myanmar | 8.5 | 9.0 | 9.5 | 47 | 41 | 36 | 0.6 | 0.5 |
| Philippines | 10.5 | 12.3 | 13.4 | 47 | 42 | 37 | 1.4 | 1.1 |
| Thailand | 19.0 | 19.9 | 19.0 | 64 | 57 | 50 | 0.4 | -0.4 |
| Vietnam | 19.3 | 22.4 | 24.6 | 61 | 53 | 46 | 1.5 | 0.9 |
| Total E. Asia | 557 | 561 | 537 | 63 | 55 | 47 | 0.1 | -0.4 |
| Total World | 1101 | 1165 | 1215 | 47 | 42 | 38 | 0.6 | 0.4 |

Farmers have historically responded to increased consumer demand in three ways: by expanding their cropped area, by increasing cropping frequency and by increasing productivity (yield per unit area) (4). In the future the majority of production increases will come from increased productivity, since there are fewer opportunities to increase either frequency or area of cropping (Table 2). Indeed, owing to our desires to conserve natural areas, intensification through increased productivity may be the most desirable option since this allows non-cropped land to be used as wildlife refuges, national parks or for recreational purposes. Extensification of production would clearly destroy key natural resources such as the tropical lowland rain forest, reducing further such areas of primary climax vegetation which are already under enormous threat of total elimination.

Table 2. Sources of growth in developing countries until the year 2010 (10).

| | Percentage of total production increase due to | | |
|---|---|---|---|
| | yields | cropped area | cropping frequency |
| 93 developing countries | 66 | 21 | 13 |
| East Asia | 64 | 27 | 9 |
| South Asia | 80 | 7 | 13 |

Therefore tropical smallholders will mostly respond to consumer demand through increasing yields and diversifying production. This response can only happen if there is a free market to provide appropriate price signals and if there are no technical, financial or social barriers to change. There are many examples which show that small farmers do respond to market signals if prices are allowed to change with demand. This however is often limited by governments which may control exchange rates, trade and pricing politics to the disadvantage of the agricultural community. Governments can assist through restraining their intervention in the market while supporting farmers through securing land tenure, providing basic education and agriculture-related training, and infrastructure for transportation (6). Increased trade is, of course, a two way process whereby increased wealth at the farm level will increase demand for agricultural equipment, fertilisers and pesticides (9).

The declining rural populations no longer allow sustainable yield increases to be achieved through intensified labour use, although this has been the most frequent approach in Asia until now. Crop yields have historically increased through better land preparation and manual weed control (6, 5, 12) as well as through improved fertilisation, pest and disease management. As labour shifts to non-agricultural sectors real labour costs rise and social expectations change. Factory work may provide higher wages and a more desirable social environment. The drudgery of some types of farm work (eg. rice transplanting, hoeing, manual weeding) may no longer be socially acceptable.

## THE USE OF HERBICIDES

Weeds are a significant constraint to increasing crop productivity and potential crop losses may be at levels of 50-95%, but reductions in yield of 10-15% are probably more common where some form of weed management is practised (12). Effects of weeds are indirect, though crop competition, and therefore their full input is not always recognised. Also national reports of crop losses due to weeds may be inaccurate or difficult to compare because of unclear methodology in assessment (11). This may make quantification of the yield losses difficult, but the severity of the problem is clear to all who have worked in tropical agriculture and a range of authors have qualitatively discussed the situation (eg. 1). An attempt to give a global evaluation of current and potential crop losses which supports such a general report has been published recently (13).

Whereever farm labour is becoming limited or where its real costs are rising then herbicide use is increasing. Effective products are generally available for the problems confronting smallholders and, where studies are available, highly attractive marginal cost benefit ratios have been demonstrated (eg. in rice (12, 15, 3)). However the use of herbicides in developing countries is small in comparison to global usage (Table 3). These figures leave two questions open: - what is limiting herbicide use in smallholder agriculture? - are there alternative approaches other than chemical intensification that can lead to higher productivity?

Table 3. Pesticide use in developed and developing countries (10).

| | Developed | Developing |
|---|---|---|
| % total of available land | 44 | 56 |
| % global use of insecticides | 50 | 50 |
| fungicides | 80 | 20 |
| herbicides | 90 | 10 |

Recent general surveys of weed management in developing countries (11, 15) may provide some indications of the barriers preventing increased herbicide use by smallholders in the Asia-Pacific region. Two general problem areas may prevent a general awareness of herbicides being translated into effective weed control:

1. Lack of knowledge
   - farmers have heard of herbicides but do not know how to use them correctly
   - serious weed problems are not correctly diagnosed
   - if the problem is recognised, it may be too late for effective control which prevents yield loss
   - herbicides are believed to damage crops
   - farmers see herbicides as a labour substitute and do not calculate their value
2. Conflict of interests
   - cash resources may be limited especially early in the season when herbicides are purchased
   - other uses of cash may be attractive
   - women may do the manual weeding, but men may control the finances and have a higher level of education
   - if labour is needed elsewhere late in the season, hand-weeding may fit better into the overall farming system
   - mechanical weeding may provide more effective weed control and at the same time prepare the seedbed or cultivate the soil

The lack of expertise in weed science and lack of funding of research and extension are basic constraints which must be alleviated (11, 2). Extension and technical service groups also need urgently to intensify their training programmes on application technique and safety. Farmers with poor application technique may cause environmental harm, may endanger human health or may distrust herbicides because of poor efficacy. However it is clear from the above analysis that the barriers which limit herbicide use are complex and require more than a technical approach if they are to be solved.

## FUTURE PROSPECTS IN WEED MANAGEMENT

There were two open questions in the previous section and one still remains unaddressed. Is there an alternative to a herbicide-based approach for intensive production systems in the tropics?

As shown previously, developing countries now start from a position of low herbicide use and therefore have an opportunity that is no longer available to developed countries where herbicide use is already high. Weed management for the tropical smallholder could be based on broad Integrated Weed Management principles where chemicals are used only as a last resort (11, 12, 2). It has been proposed that a radical departure from the methods of crop protection used in the developed world should be attempted (17, 2). For weed control this would emphasise: hand and mechanical weeding, biological control and habitat management. Others believe that this utopian vision is unrealistic for weeds and herbicides will be a major pillar of control programmes for decades to come (10).

All weed management tools have their strengths and weaknesses in their economic, societal and environmental characteristics. A possible analysis for a herbicide is shown in Table 4. In trying to maximise the benefits from a set of weed management tools we must be pragmatic and take the options to the farmer so that the smallholder can develop his/her own problem solution.

Table 4. Examples of strengths and weaknesses of chemical weed control

| | Strengths | Weaknesses |
|---|---|---|
| Economy | high / cost efficiency | reduced cash available for other purposes |
| Society | reduce drudgery of hand weeding | unemployment in the rural population |
| Environment | reduce soil erosion compared to mechanical cultivation | misuse or overuse may lead to water contamination or intoxication |

These systems for weed management will generally involve several components, including herbicides. However the chemical will rarely be the only tool for weed management, but should be used appropriately combined with other options, for example: low herbicide dosages plus limited hand weeding/mechanical cultivation, spot application where weed pressure is highest or handspraying over the row with cultivation between the rows.

Smallholders will take up new technology in order to increase profitability, but their financial base is small and they cannot afford to take large risks (14). Therefore they need support as they evaluate the effects of technology change. Farmer participation in the development of an appropriate technology package significantly improves the chances of successful implementation (16). In addition provision of correct technical information and training are essential (15). To achieve all these points, research-based industry and government extension agencies need to work together closely with their clients, the farmers. We should then have the best of all options as we combine the farmers practical and local knowledge, with industry's herbicide know-how and the agronomic base from extension scientists. Through this partnership, the combination of new technologies with traditional methods will enable the smallholder to use his weed management options effectively in order that productivity can be increased to meet the demands of his/her rapidly changing society.

This second ütopian vision is however dependent on some rather large reality checks. Table 1 shows that there are about 250 mill. people economically active in agriculture in East Asia. About 100 mill. of these could be smallholders. It requires a long-term strategic understanding to find a way of reaching this huge number of farmers with the information needed to intensify production. It requires then a further enormous effort to involve them in participatory programmes to develop and implement appropriate technologies. Industry would have to perceive that such an investment would bring commensurate long-term profits. This will need a fundamental change from the high focus on established inlets in developed countries. Governments and international bodies would have to be prepared to commit the necessary long-term funding. It is not yet clear that either party is ready to commit sufficient resources to ensure smallholders can have the opportunity to increase productivity and feed the developing world.

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# CHARACTERIZATION OF PURPLE NUTSEDGE IN RAINFED RICE-ONION SYSTEMS

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*Summary*: A survey of dominant weeds in rainfed rice-onion rotations showed that six dominant species in onion are increasing in numbers in lowland rice, with purple nutsedge as the most dominant. The lowland purple nutsedge is taller and has 60% more biomass than the upland type. When submerged in 5 cm water, tubers of the lowland type grew as well as the non-submerged plants. Tubers of the upland type submerged in 5 cm water suffered drastic reductions in growth. Morphological, physiological, and genetic studies are being conducted to determine if the lowland type is a genotype or ecotype which may have differential responses to control methods.

*Keywords*: purple nutsedge, ecotype, genotype

## INTRODUCTION

The vegetable-growing areas in San Jose, Nueva Ecija, Philippines are rainfed areas where cropping seasons are based on the annual rainfall pattern: vegetables in the dry season (December to May) and rice (*Oryza sativa* L.) in the wet season (June to November). A survey of dominant weeds in three villages in San Jose ranked purple nutsedge (*Cyperus rotundus* L.) as the second most dominant weed in lowland rice (1). In one village, it was the most dominant weed in lowland rice and consisted of 44% of the total weed population. Ten to 20 years ago, purple nutsedge was a dominant weed only in upland rice and other upland crops (3). Although its presence was reported occasionally, it was then considered only a minor weed in lowland rice (6, 7). Its increase in numbers in lowland rice over the years indicates an increasing adaptation to the alternate wet-dry soil moisture conditions in rainfed areas.

The purple nutsedge plants in lowland rice fields are taller by as much as 50% more than those in onion (*Allium cepa* L.) fields. It is not known if its increase in height is a mere morphological response to submergence or if it is an ecotype or genotype which has acquired physiological or genetic adaptations to flooding. If so, it may have different fitness or reproductive properties or differential responses to control methods.

With its underground tubers as perennial sources of propagules; purple nutsedge is the world's worst weed in vegetable crops (4). Digging the tubers and handpulling to prevent future infestations require tedious manual labor. Onion growers spend as much as US$400/ha for handweeding, increasing production costs by 20%, and making them less competitive in the world market. Its presence in lowland rice implies continued, if not increased, populations in onion. But it could also open up possibilities of control in rice which is not possible in onion due to selectivity problems.

This study was conducted to determine: 1) morphological differences in lowland and upland purple nutsedge that could indicate existence of ecotypes and 2) responses of upland and lowland types to control methods.

## MATERIALS AND METHODS

*Tuber source and plant height*: Tubers of *C. rotundus* were collected from four fields (two from Santo Tomas, one each from Palestina and Abar 1st) in San Jose during the 1995 fallow period immediately after onion harvest. The tubers were washed free of soil, placed in Petri dishes lined with moist filter paper and allowed to germinate at room temperature and natural light in the laboratory. Two to three tubers with 1-2 cm sprouts were sown into 25 cm diameter clay pots filled with loam soil. The pots were watered to saturation and placed under natural environmental conditions. When the seedlings emerged with 4-5 cm hypocotyls, pots were thinned to one plant each. One set was provided with 3-5 cm standing water stimulating flooded (lowland) soil conditions. The other set was grown in saturated well-drained soil simulating dryland (upland) soil conditions. The plants were grown under natural environmental conditions from September to November 1995 in Nueva Ecija and from December 1995 to February 1996 in Laguna. Each treatment was replicated three times and arranged in completely randomized design. Plant height was measured weekly. At 70 days after emergence (DAE) in Nueva Ecija and at 90 DAE in Laguna, the plants were harvested and fresh weights of roots, shoots, and tubers were recorded.

*Morphological characterization*: The transplant approach (growing the lowland and upland types in their opposite and natural habitats) was used to determine if the lowland type could be considered an ecotype (2). Tubers from fields 3 and 4 were grown in pots using the transplant approach. The tubers were pregerminated then sown into clay pots similar to the procedure above and grown in natural environmental condition. Tubers from plants previously grown in lowland (field 3) and upland soils in (field 4) were grown in their opposite and natural habitats. For comparison, tubers collected from dryland fields in Laguna were also grown in lowland (opposite) and upland (natural) habitat at the same time. The first set-up was grown from April to July 1996. Tubers collected from these plants were again grown in opposite and natural habitats from January 1997 to April 1997. Treatments were replicated three times in the first set-up and four times in the second set-up and arranged in completely randomized design. Plant height, number of leaves, and number of offshoots were recorded weekly. Culm diameter, length and diameter of longest leaf, number of inflorescence, and number of days to flower were also recorded. At 90 days after emergence, fresh weights of plants, and number and fresh weights of tubers were recorded.

*Tuber submergence and germination*: Tubers of the lowland (Nueva Ecija) and dryland (Los Baños) types were sown 1 cm from the soil surface into 400-ml capacity plastic cups filled with lowland soil. The cups were filled with water such that the tubers were submerged at 1-, 3-, and 5-cm water levels, resembling lowland conditions. A set of tubers watered to field capacity (saturated) resembling dryland conditions, served as the control (0 water level). The number of emerged plants, and fresh and dry weights of plants were recorded at 30 days after sowing. Treatments were replicated 10 times in a completely randomized design. The study was conducted three times from October 1996 to June 1997.

*Response to herbicides*: Tubers from lowland (Nueva Ecija) and dryland (Laguna) fields were pre-germinated, sown into clay pots and grown in natural (dryland) environmental conditions as in the previous studies. At the six to eight leaf stages, the plants were treated with recommended use rates of bensulfuron, glyphosate, glufosinate, MCPA, 2,4-D and bentazon. Treatments were replicated three times and arranged in completely randomized design. At 30 days after treatment, height and fresh weight of plants and number and fresh weights of tubers were recorded.

## RESULTS AND DISCUSSION

*Tuber source and plant height*: In the Nueva Ecija set-up, plants from fields 3 and 4 (Santo Tomas) when grown in lowland condition were 37% taller than when grown in upland condition and also 37% taller than plants from fields 1 and 2 (Abar 1st and Palestina) grown in either upland or lowland condition (Table 1). Plants from fields 1 and 2 did not increase in height whether grown in upland or lowland condition. In the Laguna set-up, plants from fields 3 and 4 grown in lowland conditions were taller by 63% than plants from fields 1 and 2 (Table 1). In upland conditions, fields 3 and 4 plants were taller than fields 1 and 2 plants by 47%.

Averaged across locations, purple nutsedge from fields 3 and 4 (Santo Tomas) increased in height by 34 to 37% in lowland compared to upland condition. These plants were also 40 to 60% taller than purple nutsedge from field 1 (Abar 1st) and field 2 (Palestina) whether the latter were grown in upland or lowland condition. The ability to grow taller in lowland condition was not observed in fields 1 and 2 plants. Variations in height were more distinct in the Laguna set-up than in Nueva Ecija set-up.

Table 1. Height of *C. rotundus* collected from four fields in San Jose, Nueva Ecija and grown in flooded (lowland) and saturated (upland) soil in two locations.

| Water level/ Field | Source | Plant height (cm) | |
|---|---|---|---|
| | | Nueva Ecija | Los Baños |
| Saturated (0 cm) | | | |
| 1 (Pascual) | Abar 1st | 47 | 23 |
| 2 (Fajardo) | Palestina | 50 | 25 |
| 3 (Salazar) | Sto. Tomas | 50 | 44 |
| 4 (Hipolito) | Sto. Tomas | 53 | 45 |
| Flooded (5 cm) | | | |
| 1 (Pascual) | Abar 1st | 45 | 22 |
| 2 (Fajardo) | Palestina | 58 | 28 |
| 3 (Salazar) | Sto. Tomas | 82 | 70 |
| 4 (Hipolito) | Sto. Tomas | 83 | 64 |

*Morphological characterization*: Regardless of their previous growing conditions, plants from fields 3 and 4 were taller and produced more leaves and offshoots, bigger culms, longer and bigger leaves, more flowers, bigger tubers, and generally had 60 to 76% more biomass when grown in their natural (lowland) habitat than in their opposite (upland) habitat (Table 2). In comparison, plants collected from upland fields in Laguna did not change in height whether grown in their natural (upland) or opposite (lowland) habitat. However, these plants, when grown in lowland (opposite) habitat also produced more leaves and offshoots, bigger culms, more flowers, more and bigger tubers and had 56% more biomass than the plants grown in upland (natural) habitat (Table 2). These results confirm the results of the earlier study where *C. rotundus* from two fields in Nueva Ecija grows bigger and taller in lowland soil than in upland soil. Under lowland conditions, the lowland *C. rotundus* reached a height of 94 to 102 cm, which is about the height of rice (Table 2).

In Japan, Thailand and the Philippines, the existence of a lowland ecotype of purple nutsedge has been reported (2, 4). Similar to our results, the lowland type previously reported produced taller plants, more dry matter, and bigger tubers in lowland conditions (natural habitat), while growth was markedly reduced when grown in upland conditions (opposite habitat).

Table 2. Growth parameters of *C. rotundus* grown in upland and lowland conditions

| Growth Parameter | LB (U)[a] | | | NE (L)[a] | | | NE (U)[a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | L[b] | U[b] | Diff (%)[c] | L[b] | U[b] | Diff (%)[c] | L[b] | U[b] | Diff (%)[c] |
| Height (cm) | 65 | 67 | 3 | 94 | 85 | 10 | 102 | 74 | 27 |
| Weight (g) | 347 | 154 | 56** | 294 | 119 | 60** | 504 | 120 | 76** |
| No. of offshoots | 51 | 22 | 57** | 29 | 16 | 45** | 43 | 20 | 53* |
| Culm diam. (mm) | 23 | 15 | 35* | 22 | 16 | 27* | 23 | 15 | 35* |
| No. of leaves | 459 | 242 | 47** | 261 | 144 | 45** | 387 | 180 | 53* |
| Leaf length (cm) | 35 | 33 | 6 | 52 | 44 | 16* | 48 | 38 | 21* |
| Leaf diam. (mm) | 6 | 6 | 0 | 8 | 5 | 38* | 6 | 5 | 17 |
| No. of inflorescence | 17 | 8 | 53 | 15 | 9 | 40 | 19 | 6 | 68 |
| Days to flower | 38 | 37 | (1) | 40 | 32 | (8) | 42 | 42 | (0) |
| No. of tubers | 59 | 39 | 34 | 30 | 27 | 10 | 42 | 43 | 2 |
| Wt. of tubers (g) | 51 | 31 | 39 | 33 | 27 | 18 | 46 | 28 | 39 |
| Wt./tuber (g) | 0.86 | 0.79 | 8 | 1.1 | 1 | 9 | 1.1 | 0.65 | 41 |

[a] Average of four replications; LB (U) = tubers collected from Los Baños, Laguna (upland); NE (L) = tubers collected from San Jose, Nueva Ecija, previously grown in lowland soil; NE (U) = tubers collected from San Jose, Nueva Ecija previously grown in upland soil.

[b] L = grown in lowland condition; U = grown in upland condition

[c] Indicates percent difference between plants grown in upland and lowland soil within a location/tuber source; *significant; ** highly significant at 5% level.

*Tuber submergence and germination*: Data are averages of three trials (Table 3). Tubers of both upland and lowland types sprouted and emerged at all water levels. However, height of upland plants submerged in 1 to 5 cm water was reduced by 15 to 27% compared to those grown in saturated soil. The biomass of these plants were reduced by 30% at 1 to 3 cm submergence and by 60% at 5 cm submergence compared to upland plants grown in saturated soil. Height and weight of lowland plants submerged in 1 to 5 cm water was reduced by an average of 9% compared to those of lowland plants grown in saturated soil. Those submerged in 5 cm water were as tall as the non-submerged plants, while those submerged in 1 cm water had the same biomass as the non-submerged plants. This suggests that tubers of lowland plants can sprout, emerge and grow well even at 5 cm submergence. Upland plants can also sprout and emerge in submerged conditions but with drastically reduced growth.

Table 3. Height and fresh weight of lowland and upland plants germinated and grown at different water levels. (Average of 3 trials, 10 replications per treatment; numbers in parenthesis indicate % difference from 0 water level).

| Water Level (cm) | Height (cm) | | Fresh Weight (g/plant) | |
|---|---|---|---|---|
| | Lowland | Upland | Lowland | Upland |
| 0 | 29.4 | 24.3 | 9.1 | 8.0 |
| 1 | 26.0 (11) | 17.8 (27) | 9.5 (0) | 5.3 (34) |
| 3 | 24.3 (17) | 20.6 (15) | 7.9 (13) | 5.5 (31) |
| 5 | 30.8 (0) | 18.5 (24) | 7.7 (15) | 3.2 (60) |

*Response to herbicides*: 2,4-D, glufosinate and glyphosate completely killed *C. rotundus* plants and tubers (Table 4). Bentazon, bensulfuron, and MCPA significantly suppressed growth but did not kill the plant nor the tubers. Plants in these treatments still produced a few tubers. One to two of the tubers treated with bensulfuron and MCPA were able to produce sprouts. Similar responses were observed in both upland (Laguna) and lowland (Nueva Ecija) plants.

Table 4. Effect of six herbicides on plant fresh weight and tuber production of *C. rotundus*

| Treatment[a] | Fresh Weight (g/plant) | | No. of Tubers (no/plant) | | No. of Tubers with Sprouts | |
|---|---|---|---|---|---|---|
| | LB[b] | NE[b] | LB | NE | LB | NE |
| 2,4-D | 0 b[c] | 0 b | 0 d | 0 d | 0 b | 0 b |
| glufosinate | 0 b | 0 b | 0 d | 0 d | 0 b | 0 b |
| glyphosate | 0 b | 0 b | 0 d | 0 d | 0 b | 0 b |
| bentazon | 1.0 b | 0.8 b | 0.5 d | 1.0 cd | 0.3 b | 0 b |
| bensulfuron | 3.7 b | 4.1 b | 4.0 bc | 3.0 bcd | 2.0 b | 1.0 b |
| MCPA | 3.2 b | 3.1 b | 3.0 bcd | 3.0 b | 2.0 b | 0.5 b |
| Untreated | 17.6 a | 18.0 a | 9.0 a | 5.0 b | 5.0 a | 3.0 ab |

[a] Applied at recommended use rates at 6-8 leaf stage; average of 4 replications.
[b] LB = tubers collected from Los Baños and grown in upland condition; NE = tubers collected from Nueva Ecija and grown in upland condition.
[c] Within a growth parameter, numbers followed by the same letter are not significantly different at 5% level of DMRT.

*General discussion and conclusions*: The existence of a lowland ecotype of purple nutsedge has been reported in Asia since the 1950s (2, 5). This study reports its increasing numbers in rainfed lowland rice rotated with onions and other vegetables in a regular annual cycle in the Philippines. Of four farmers' fields in San Jose, Nueva Ecija, Philippines, lowland purple nutsedge was shown to occur in two fields. Greenhouse studies are being conducted to determine if the lowland type also occurs in ten other fields located in three villages in San Jose.

The lowland type was shown in greenhouse studies to grow much taller and bigger than the dryland type. Tubers of these plants submerged in 5 cm water sprouted, emerged and grew as well as non-submerged plants. Submerged tubers of the upland type also sprouted and emerged but its subsequent growth was reduced by as much as 60 % compared to growth of non-submerged tubers. Genetic and physiological studies are being conducted to determine if the lowland type is a genotype with possible differential responses to control measures or different fitness or reproductive properties.

The alternate wet-dry soil moisture regimes repeated in an annual cycle continously over the years is apparently selecting for a type of purple nutsedge that can grow in both water regimes. Over time, this could result in dominant species shifts. Presence of the lowland purple nutsedge in rice indicates increased infestation in onions. But it could also open up possibilities of control in rice which are not possible in onion due to selectivity problems.

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# POPULATION INCREASE RATES OF *NEOCHETINA EICHHORNIAE* WARNER AND *N. BRUCHI* HUSTACHE (COLEOPTERA: CURCULIONIDAE) ON *EICHHORNIA CRASSIPES* (MART.) SOLMS. IN TAIWAN

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*Summary:* Population increase rates of *Neochetina eichhorniae* (NE) (1.0736 weevils/♀/day), *N. bruchi* (NB) (1.0725 weevils/♀/day) and water-hyacinth (WH), *Eichhornia crassipes* (1.7385 offspring/plant/week) were estimated with regression analyses in the ponds. The carrying capacity of NE and NB were ranging from 1.096 to 1.410 weevils/plant. An average ratio was 0.191±0.001 adults/larvae in the plants; an average of 0.519 harvested-weevils/replenished-weevils were evaluated with an average damage-rate of the weevils at -1.007 plants/m$^2$/week. A density of one larva per plant significantly caused 2.796 and 4.671 times reduction of the leaves and biomass in 1 month, respectively, and completely destroyed the plant in 3 months.

*Keywords*: biocontrol, *Neochetina*, water-hyacinth

## INTRODUCTION

Water-hyacinth, *Eichhornia crassipes* (Mart.) Solms., indigenous to the Amazon River, is one of the most notorious water weeds (11, 14). It infested 476 water-ways and reservoirs with 611 ha. coverage in Taiwan (1). The biomass and population of water-hyacinth increases in an extremely fast rate to impede the water-way or irrigation gate (13). The rapid increase rate of water-hyacinth made mechanical control non-economical. Whenever chemical control was adopted, water and environmental pollution increased (12, 15). Biological control of water-hyacinth was intensively implemented from 1960-1980 (2, 8, 9, 16, 17, 18). The major and effective natural enemies of water-hyacinth include fungi, bacteria, snails, and insects (2, 6, 10, 18). The most successful natural enemies of insects are *Neochetina* spp., *Sameodes albiguttalis* and *Engaurax setigena* (3, 5, 7 ,8, 10, 17, 18). *Neochetina* spp. injured the water-hyacinth leaves which, withered and induced death of the plants. A 100% of control of water-hyacinth in the water-way has been economically demonstrated with the introduction of insect natural enemies.

The minute size and imperceptibility of eggs and larvae in the plant tissue made it difficult to study the individual life history and to construct the life table of the weevils. Therefore, there is no report on the age specific fecundity of weevils to estimate the net reproductive rate ($R_0$) and population increase rate ($r_m$). In this study we estimated the population increase rate of the water-hyacinth, and weevils (*Neochetina eichhorniae* (NE) and N. *bruchi* (NB)) using regression models and demonstrated the mass rearing of weevils with the amount of water-hyacinth added in a limited rearing unit.

## MATERIALS AND METHODS

A total of 80 10~11-leaf water-hyacinths was transferred into each of 8 saran-covered-ponds (220x246x142 cm). Eight ponds were randomly divided into two groups. Four ponds were used to rear NE and the other four ponds were used to rear NB. Each pond was inoculated with 20 pairs of either 4-day old NE or NB of 4-day-old to make density at 0.25 weevils/plant. After 40 plants were removed from the pond and kept separately in another 10x5x1 m pond, the same amount of plants were added into each pond to replenish the food resources for the weevil every week. Starting at 3 or 5 days after the inoculation of the weevils, we sampled the numbers of the plants and adult weevils every 7 days for NE and NB densities, respectively. The total numbers of adult weevils from both types of ponds of the same origin were fitted with linear, sigmoid and disk equation models. Two water-hyacinth plants from each pond were also randomly sampled and dissected to assess the eggs and larvae in the plant tissue under a 20 x dissection microscope. The eggs and larvae from the same plant were transferred and embedded in the tissue of a new plant in an aquarium (60x30x33 cm). These weevils were reared to adults to assess the injury and damage of the weevils to the plants. Whenever the plant died in the aquarium, an additional plant was replenished for the weevil's food-resource. We assessed the numbers of leaves and weighed biomass of the plants every 2 weeks on weevil-inoculated plants from the aquarium and non-weevil inoculated plants from the ponds.

When a total of 90 water-hyacinth plants of 6~7 leaves in either one of 8 saran-covered ponds grew to 9~11-leaf stage, we transferred 80 pairs of adult-weevil into each pond. Additional 30 new 9~11-leaf plants were added weekly after the same numbers of plants with weevils were removed and sampled every 2~3 weeks. The adult weevils were assessed and removed from the ponds. The eggs and larvae were also assessed by dissecting the plant tissues and then re-inoculated into the ponds. The larvae densities and the number of scars on the leaves and petioles were correlated with the densities of adults. The results of the cumulative numbers of harvested adults to the amount of water-hyacinth (9~11 leaves) plants added were fitted with a linear regression model to find the population harvest rate to the food resources added. Correlation coefficient analyses were also made on the densities of the adult weevils to the densities of scars (4).

## RESULTS AND DISCUSSION

*Population growth rates and theoretical estimated carrying capacity of NE and NB on water-hyacinth*: The transparent, whitish, and minute eggs of NE and NB, laid in the leaf tissue, that they could only be assessed under a spot light and microscope. The first instar larvae were also minute and imperceptible with a high mortality rate when they were dissected and removed from the tissues for assessment. The mature larvae pupated under the water and the pupae would die when they were removed out of the water. Therefore the dissection and destruction of plant sampling-procedures to assess the eggs and larvae made the sample non-repeatable and limited the sample size in this study. There is no report, so far, on the population increase rate of weevils and very limited replicates for life table or life history trials reports among the studies. Nevertheless, the population increase rates of the NE and NB were estimated by regressing the data from saran-covered-ponds with linear, sigmoid and disk models (Table 1, Figs. 1 & 2).

Table 1. Estimations of population increase rates and carrying capacities of *Neochetina eichhorniae* and *N. bruchi* with regression equations on water-hyacinths

| | Estimated regression equations | |
|---|---|---|
| Regression equations | *N. eichhorniae* (No. weevils/plant) | *N. bruchi* (No. weevils/plant) |
| Linear model | $Y=0.244+0.020*t$ | $Y=0.242+0.021*t$ |
| $Y=a+bt$ | $R^2=0.927$, $P=0.001$ | $R^2=0.930$, $P=0.001$ |
| Sigmoid model | $Y=1.176/(1+3.152*e^{0.071*t})$ | $Y=1.096/(1+2.720*e^{0.070*t})$ |
| $Y=b_0/(1+b_1e^{b2*t})$ | $R^2=0.999$, $P=0.001$ | $R^2=0.994$, $P=0.001$ |
| Disk model | $Y=(0.071*t)/(1+0.071*0.711*t)$ | $Y=(0.070*t)/(1+0.070*0.706*t)$ |
| $Y=b_0t/(1+b_0b_1t)$ | $R^2=0.998$, $P=0.001$ | $R^2=0.999$, $P=0.001$ |
| Population increase rate | | |
| Coefficient $b_2$ of sigmoid equation ($b_2$) | $b_2= 0.071$ | $b_2= 0.070$ |
| Carrying capacity (K) | | |
| $b_0$ of sigmoid equation | $b_0= 1.176$ | $b_0= 1.096$ |
| $1/b_1$ of disk equation | $1/b_1 = 1.406$ | $1/b_1= 1.416$ |

The disk equation with the highest R-square values (0.998 for NE and 0.999 for NB) was the fittest among all regression equations (Table 1, Figs. 1 & 2). The results of fitting regression equations of NE and NB by sigmoid model also showed a high R-square value. The population increase rates of NE and NB were 0.071 and 0.070, respectively, which were estimated from the $b_2$ of the respective sigmoid equations (Table 1). The theoretical maximum density of the weevil's population (Y) estimated from the denominator of the sigmoid equations ($b_0$), i.e., carrying capacity of each water-hyacinth plant (K), was 1.176 weevils / plant for NE and 1.096 weevils / plant for NB; while calculated K values by the reciprocal value of $b_1$ ($1 / b_1$) from disk equations were 1.406 weevils / plant (1 / 0.711) for NE and 1.416 weevils / plant (1 / 0.076) for NB (Table 1). We conclude that NE population increased slightly faster than NB population and it would theoretically reproduce slightly higher population numbers of NE than NB on the same amount of water-hyacinth offered in a pond, if we employed the evaluation with denominator of the sigmoid equations. When we employed the reciprocal value of $b_1$ from disk equation, the maximum number of weevils per plant of NE was less than NB. However, we are obliged not to speculate any interpretation of competition between the populations of NE and NB. Dissecting the water-hyacinth plant to evaluate the numbers of larvae associated with the numbers of adult weevils on the plant, we found the ratio between the adults and larvae in the pond-reared population was 0.191 (1 / 5.235) ± 0.001 (mean ± SD).

The population growth of the water-hyacinth and mass reproduction of *N. eichhorniae* and *N. bruchi*: After 3-week growth in the ponds of 5x10x1 m, the population growth data of water-hyacinth was employed with either exponential or linear function (Fig. 3). The linear regression equation estimated for the plant increases was significant but with 0.793 R-square value and an estimated increase rate equal to 14.441 (Y (plants) = -16.754 + 14.441 * weeks (R-square = 0.792, p = 0.003)) (Fig. 3). The exponential growth function of the plants growth was better fitted and determined by a higher R-square value (Y (ln (plants)) = 3.229 + 0.553 * ln (weeks) (R-square = 0.989, p = 0.001)) (Fig. 3).

Therefore, the water-hyacinth population increased with an exponential function The numbers of cumulative weevils harvested in a rearing pond were increased with the amount of the water-hyacinth plants replenished (Fig. 4). The cumulative-harvest numbers of the weevils showed a linear function to the cumulative numbers of plants replenished (Y = 17.558 + 0.519 * X (R-square = 0.985, p = 0.001)) (Fig. 5). A removal and replenishment of one third to half of the plants from and into the pond, respectively, would reproduce 0.519 weevils with each water-hyacinth plant replenished (Fig. 5).

*Assessment of injury and damage of water-hyacinth:* Water-hyacinth population and biomass grew in an exponential function (Figs. 3 & 4); two *Neochetina* species reduced not only the plant numbers but also the increase rate. Adult weevils nipped the epidermis and tissues of the leaves and the petioles to leave scars on the leaves, and the larvae bored and tunneled inside the petiole down to the stem. The growth of the plant was stunted. The larvae inside the stem and petiole could not be inspected to assess the damages until the plants were dissected. Wright and Center (18) demonstrated the positive correlation between the scars and the densities of the weevils. We found the average numbers of adults to larvae in plants was at a ratio of 1 / 5.235 (0.191 ± 0.001, mean ± SD). Therefore, we assume that the scars are significant to represent the densities of the weevils in the plants and we use the scars as indices for the total injuries caused by the adults and the larvae. The higher the numbers of scars, the higher the densities of weevils and the higher intensity of the injury, the lower the plant densities in the ponds (Figs. 6 & 7). An inverse relationship between the injury of the weevils, i.e., nipping, tunneling and eating the leaves' epidermis and tissues, and the densities of water-hyacinth was evaluated by a linear regression equation (Y = 63.352 - 1.007 * X (R-square = 0.803, P = 0.001)) (Fig. 7).

Selecting 40 one-larva-tunneled plant during the sampling, we weighed and counted the numbers of leaves of each plant. The weevils damaged the plant and made an average of 2.7 times reduction in leaf-numbers (reducing from 13.7±2.496 leaves / plant to 4.9±2.884 leaves / plant) or 4.5 times of reduction of biomass (reducing from 184.5 gm / plant to 22.79 gm / plant) in one month (Table 2). The water-hyacinth plant died within 3 months with one-weevil-injury per plant and the plant's biomass reduced to a remnant (0.1±0.316 leaf / plant and 6.0±12.65 gm / plant) (Table 2). We demonstrated that the weevils injured the water-hyacinth plant and significantly damaged the plant in one month and totally destroyed the plant in 3 months. The higher the density of the weevil per plant, the higher the damage (Table 2, Fig 7).

Table 2. The effects of *Neochetina eichhorniae* damages the biomass and leaves of water-hyacinth

| Treatments | N | Days after release | Numbers of leaves/plant mean | Numbers of leaves/plant SD | Weight (gm)/plant mean | Weight (gm)/plant SD |
|---|---|---|---|---|---|---|
| Control | 10 | 0 | 9~10 | | 95.5 | |
| | 10 | 1 month | 13.7a | 2.496 | 184.5a | 22.79 |
| Released | 10 | 1 month | 4.9b | 2.884 | 39.5b | 32.95 |
| | 10 | 1 month | 0.1c | 0.316 | 6.0c | 12.65 |

1. Means in the same column followed by same letter are not significantly different by least significant difference test at p = 0.05.

*N. eichhorniae* maximum density per plant (K = 1.176 by sigmoid equation and K = 1.406 by disk equation) and population increase rate (r = 0.071) are almost equal to those of *N. bruchi* (K = 1.096 by sigmoid equation, K = 1.410 by disk equation and r = 0.070). We speculated that *N. eichhorniae* made no difference in carrying capacity and population increase compared to *N. bruchi*. Therefore, if we use the weevils for biological control of water-hyacinth in the field, we recommend to employ both species of weevils instead of one.

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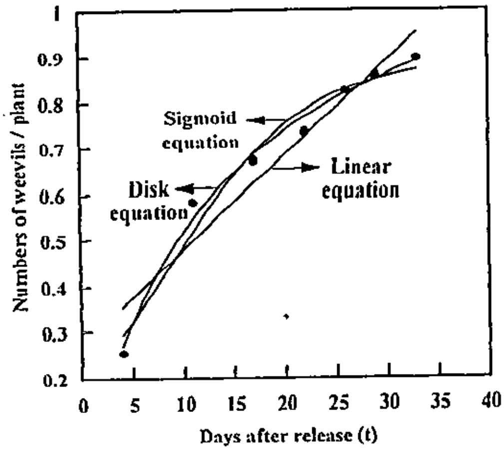


Fig.1. Population growth of *Nneochetina eichhorniae* on water-hyacinth plants in saran-covered ponds.

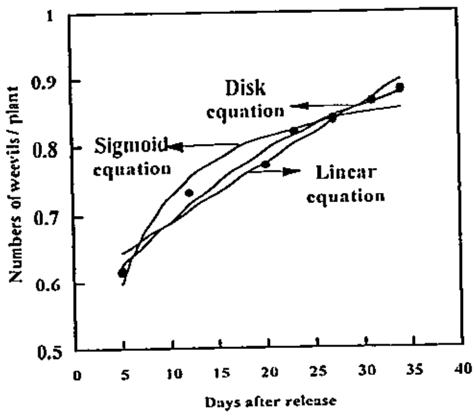


Fig.2. Population growth of *Neochetina bruchi* on water- hyacinth plants in saran-covered ponds.

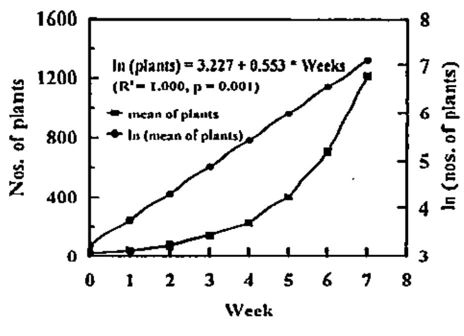


Fig.3. Plant population increase rate of water-hyacinth

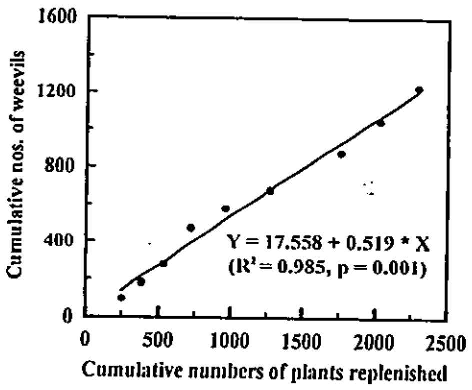


Fig.5. The estimated linear regression equation for the effects of the cumulative numbers of water-hyacinth plants replenish on the cumulative numbers of adult-weevils harvested

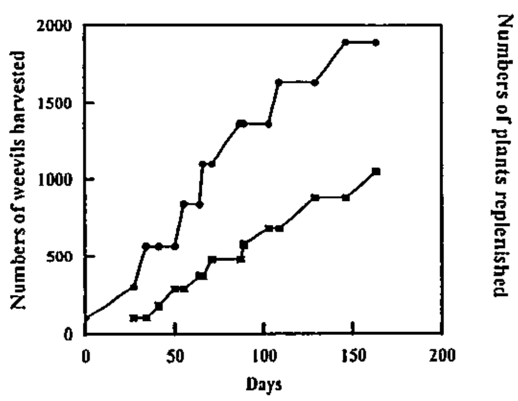


Fig.4. The relationship between the cumulative numbers of adult weevils harvested (●)and the amount of water-hyacinth plants replenished (■)in the saran-covered ponds (220x246x142cm)

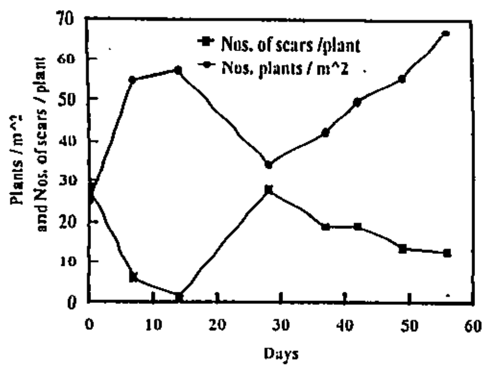


Fig. 6 . The relationship between the feeding-scars of weevils (scars / plant) and water-hyacinth densities (plants / $m^2$) in ponds (5x10x1m)

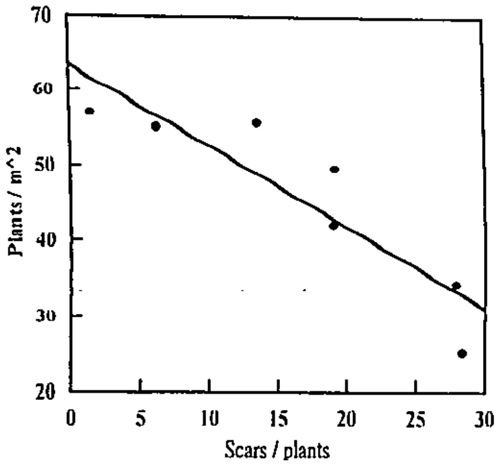


Fig. 7. The influences of the scars of the weevils' injuries to the densities of water-hyacinth in saran-covered ponds ($Y = 63.352 - 1.007 * x$ ($R^2 = 0.803$, $p = 0.001$))

# ALLELOPATHY IN *CHENOPODIUM PUMILIO*: A SERIOUS BUT MANAGEABLE PROBLEM

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*Summary*: *Chenopodium pumilio* R. Br. was investigated to minimise its allelopathic impact on crops and pastures in Western Australia. It was shown that early control of this weed is one option to allow sufficient breakdown of the allelochemicals to a level that is non-injurious to subsequent crops and pastures. Another option is to delay sowing to allow sufficient rainfall to dilute and leach the allelochemicals from the seed zone. The amount of rainfall required to leach the allelochemicals from known amounts of goosefoot residues is currently under investigation and it is anticipated that such information would serve as a useful advisory aid for farmers.

*Keywords*: allelopathy, *Chenopodium pumilio*

## INTRODUCTION

There have been concerns that the no-till farming practices in Western Australia may be thwarted by the allelopathic potential of toxic weeds, crop stubbles and pasture litter. *Chenopodium pumilio*, commonly known as goosefoot, has been confirmed to have allelopathic potential. Goosefoot is a major summer weed in the Western Australian wheatbelt, especially following adequate spring and summer rainfalls. Because of its ability to grow until the time of crop sowing in late autumn and early winter, goosefoot has caused serious establishment problems to crops and pastures by releasing allelochemicals into the soil (1). So far, several chemicals capable of inhibiting germination and seedling growth have been isolated and identified (2). Despite the serious damage caused by goosefoot, the damage was not consistent in all years. The most acute damage usually occurs following dry summers and autumns especially in first opportunity planting. Factors such as early control of the weed followed by adequate rainfall, have been observed to alleviate the toxicity problem. These field observations clearly suggest the importance of early control and the need to consider the impact of the timing and amount of rainfall when assessing the potential threat of goosefoot in any one year.

The aims of the work reported here were to determine the effects of time of control of goosefoot and time of crop sowing upon the survival of wheat, lupins, canola and pastures.

## MATERIALS AND METHODS

*Time of control experiment*: Four separate dates of control of goosefoot were compared: February (4 months before crop seeding); March (3 months before crop seeding); April (2 months before crop seeding); and June (at the time of crop seeding). On each date, enough goosefoot plants were sprayed with 1L/ha of Spray.Seed® (125 g/L paraquat as paraquat dichloride and 75 g/L diquat as diquat dibromide monohydrate) to allow the following treatments:

(i) residues at normal field rate (1 kg fresh wt/$m^2$);
(ii) residues at half normal field rate (0.5 kg fresh wt/$m^2$);
(iii) residues at twice normal field rate (2 kg fresh wt/$m^2$);
(iv) no goosefoot control.

Each treatment was replicated six times in a randomised complete block design. In June , when the soil was moist enough, wheat, lupins, canola and pasture species (50 seeds each) were sown into each of the four treatments. At two-weekly intervals after sowing, the number of healthy seedlings was recorded. The results were expressed as a percentage of the control.

*Time of sowing experiment* : Goosefoot plants previously killed with Spray.Seed® were laid out in the field at the start of the cropping season to allow the following main treatments:

(i) residues at normal field rate (1kg fresh wt/$m^2$);
(ii) residues at half normal field rate (0.5 kg fresh wt/$m^2$);
(iii) residues at twice normal field rate (2 kg fresh wt/$m^2$);
(iv) no goosefoot control.

At 0, 1, 2, 3, and 4 weeks after break of season, wheat, lupins, canola and pasture species (50 seeds each) were sown into each of the main treatments. All treatments were replicated three times in a split-plot design where sub-plots were times of sowing and crop type. At two-weekly intervals after each sowing, the number of healthy seedlings was recorded and the results were expressed as a percentage of the control.

## RESULTS AND DISCUSSION

In the time of control experiment, enough rain had fallen to allow leaching of the allelochemicals from the seed zone by the time crops and pastures were seeded into the weathered goosefoot residues. In contrast, goosefoot plants that were sprayed in June just before crop seeding, still retained their toxicity to cause significant damage to the emerging crops and pastures (Figure 1). There was an increase in damage with an increase in the goosefoot concentration.

The important role of rainfall was confirmed in the time of sowing experiment. When crops and pastures were seeded immediately into the goosefoot residues at the break of the season, there was considerable damage to their establishment (Figure 2). A week delay in sowing resulted in the establishment of healthy wheat and lupin crops. The more sensitive canola and legume pastures required at least two weeks delay to obtain a good crop. The critical amount of rainfall appeared to be between 50 and 100 mm. However, more data are required before we can advise farmers on the amount of rainfall required to leach the allelochemicals from known amount of goosefoot residues.

Overall, the results have confirmed that the timing of goosefoot control is important, so as to allow the decomposition of the residues and the allelochemicals before sowing. Generally, plants killed at least two to three months before crop sowing are more likely to receive enough rainfall to allow decomposition and leaching of the allelochemicals. Rainfall plays a prominent role because of the high solubility of the goosefoot allelochemicals in water. Thus, a delay in sowing can help to overcome the toxicity problem following a good opening rain as illustrated by the results.

Considering the risk of crop failure in relation to its degree of tolerance to the goosefoot allelochemicals, the results have shown that canola is the least tolerant species and that wheat is generally more tolerant than lupins. This knowledge will help farmers in their decision on choice of crops when seeding in areas where goosefoot is a problem. Although there are varietal differences in tolerance within each crop, no variety has been found, so far, to have extreme tolerance.

## ACKNOWLEDGEMENTS

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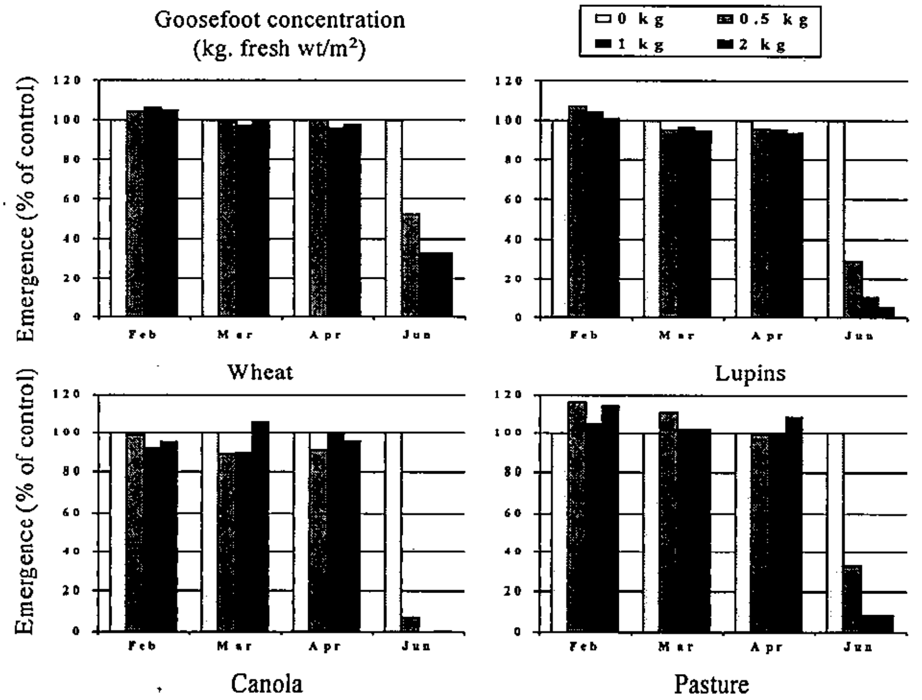


Figure 1. Effects of time of control of goosefoot on the emergence of wheat, lupins, canola and pasture.

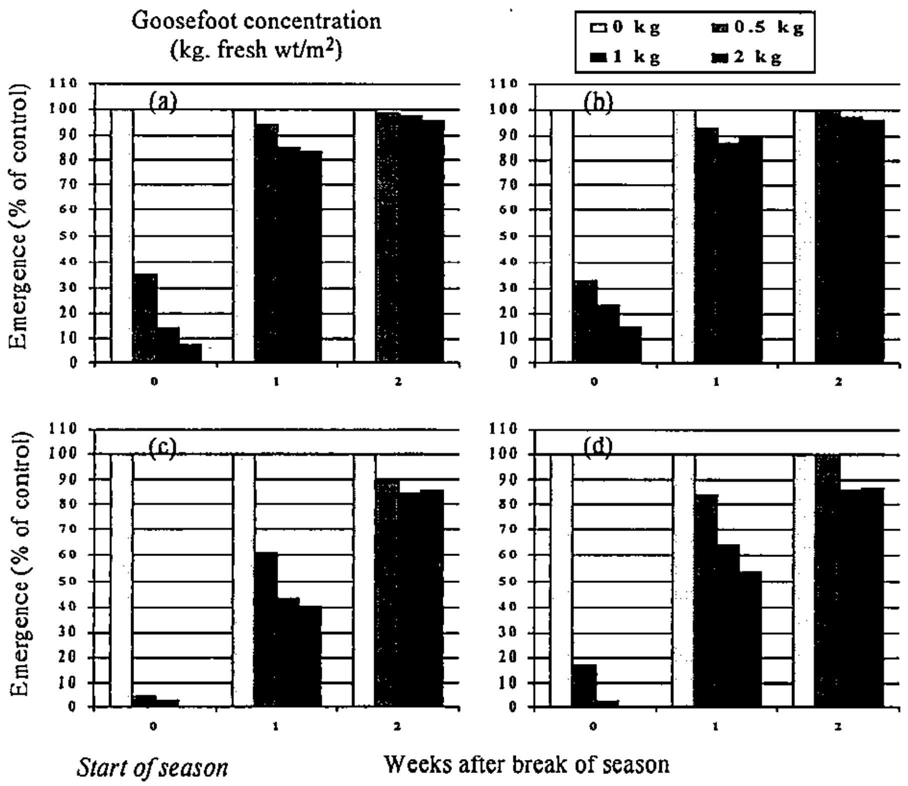


Figure 2. Effects of time of sowing on the emergence of wheat (a), lupins (b), canola (c) and pasture (d) in goosefoot residues.

# ACTIVITY AND ALLOCATION PATTERN OF ALLELOCHEMICALS IN *LYCORIS RADIATA* HERB.

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*Summary:* Three organs of *Lycoris radiata* Herb., scaly leaf, scaly bulb and flowering scape were studied to elucidate their allelopathic effect on neighbouring plants. The activity of water extract obtained from equivalent fresh weight was highest in scaly bulb, followed by scaly leaf and flowering scape. According to the estimate allelochemicals contained in each organ per unit area, scaly bulb and scaly leaf have potentiality to exhibit allelopathy in the field. About three fourth of allelochemicals in scaly leaf was rapidly released in a short period when scaly leaf died from May to June. 0Scaly bulb constantly released allelochemicals enough to inhibit the radicle growth of lettuce under two week-wet soil conditions. Thus, scaly bulb looks a key organ for allelopathy in *L. radiata* because it exists in the soil in all seasons. Studies on allocation patterns of allelochemicals and dry matter showed that allelochemicals were allocated to scaly bulb more intensively than dry matter. Therefore, *L. radiata* appeared to have a desirable allocation pattern of allelochemicals to inhibit the growth of neighbouring plants in the field.

*Keywords:* allelopathy, allocation, *Lycoris radiata* Herb.

## INTRODUCTION

*Lycoris raditla* Herb. is one of the well-known species suppressing its neighbouring plants by allelopathy. The scaly bulbs buried in soil at a density higher than 50% significantly inhibit the number and growth of neighbouring plants even in the dormant state of this species (5, 3). More than 90% inhibition of the growth is observed with 100 % density of scaly bulb. Bioassay with water extracts from the scaly bulb has proved that the scaly bulb contains the allelopathic substances. These are the evidences for allelopathy of scaly bulb of this species. However, the role of other organs such as scaly leaf and flowering scape in allelopathy is not clear yet although allelochemicals are considered to distribute all through the plant body (1, 2, 4, 6).

In this report, at first, potentiality of allelopathy of scaly leaf and flowering scape was compared to scaly bulb. Secondly, allocation pattern of allelochemicals to those organs was compared to the energy allocation pattern of this species. Based on these results, the role of each organ in allelopathy of this species is discussed.

## MATERIALS AND METHODS

*Allelopathic activity of scaly leaf, scaly bulb and flowering scape*: Water extracts from fresh materials of scaly leaf, scaly bulb and flowering scape were bioassayed with lettuce *(Lectuca scaliora* L.) in 5% agar substrate. The fresh materials of scaly leaf and scaly bulb were collected from a paddy levee in Zentsuji, Kagawa, Japan, in April, 1996, and those of flowering scape were in November. Ten g of the materials was ground in a mortar, -allowed to stand in 300 ml distilled water for 24 h to-extract allelochemicals. The water samples were filtered off impurities with a double folded gauze and regarded as the standard extracts (X). Several dilutions of the standard extracts, 1/2X, 1/4X and so on, in which agar was added to 5% in solution, were bioassayed to compare the intensity of allelopathic activities of three organs on fresh weight basis. Allelopathic activity was estimated from the inhibition of radicle length of lettuce seeds incubated at 20°C for 7 days after planting. Allelopathic activities of those organs were also compared in soil substrate in the same way except that water extracts (15 ml) were applied to the soil surface. Two field soil samples were taken on July 18 from a paddy levee covered by scaly leaves and from a paddy field. Those soil samples were bioassayed with lettuce to detect the allelopathic activity from scaly leaf in the field.

Activity of allelochemicals released from scaly bulb into soil was tested, using a scaly bulb planted in a centre of a 300 ml beaker filled with soil. The beaker was left in an incubator at 20°C for 2 weeks after watering up to saturated conditions. Lettuce seeds were planted in the soil from a centre (edge of a scaly bulb) to the edge of the beaker at 2 mm intervals. Three rows were made as replications. Allelopathic activity was estimated as described above.

*Seasonal change in allelopathic activity of scaly leaf, scaly bulb and flowering scape*: Scaly leaf, scaly bulb and flowering scape were collected once or twice a month from a paddy levee as above from February to June and from September to January. Those samples were dried up in an oven at 80 °C for three days. Dry materials equivalent to 10 g fresh organs were weighed, and ground in a mortar. Allelopathic activities of those dry materials were compared by $ED_{50}$ in radicle length of lettuce in a bioassay with agar substrate, as described in Fig. 1. Allocation of allelochemicals to each organ was estimated from the ratio of dry weight of each organ providing $ED_{50}$. Two allocation patterns of allelochemicals and dry weight were compared.

## RESULTS AND DISCUSSION

The activity of water extract from fresh materials per unit weight was highest in scaly bulb both in agar and soil substrates, followed by scaly leaf and flowering scape. The activity in soil was about 1/16 of that in agar substrate. The activity of scaly bulb was about two times higher than that of scaly leaf, and was four times higher than flowering scape (Fig. 1). According to the relationship between fresh weight and its treated area, scaly leaf at 0.87 kg/m$^2$ should inhibit the growth of lettuce and crabgrass (Fig. 2). Because the fresh weight of scaly leaf is 6.9 kg/m$^2$ on average in this region, only 12.6% of the total amount of scaly leaf growing in its habitat should be required for its allelopathy (Table 1). As for scaly bulb, much less than that (2.6%) is necessary for allelopathy. These results-suggest that scaly leaf and scaly bulb are likely to be sources for inhibiting neighbouring plants by allelopathy.

Fig. 3 shows the seasonal change in allelopathic activity of scaly leaf during its dying period. About three fourth of allelochemicals were rapidly lost in scaly leaf from May to June in which rainy season starts. Considered that scaly leaf quickly releases its allelochemicals into water in its dying period, the dissipation - of allelochemicals from scaly leaf

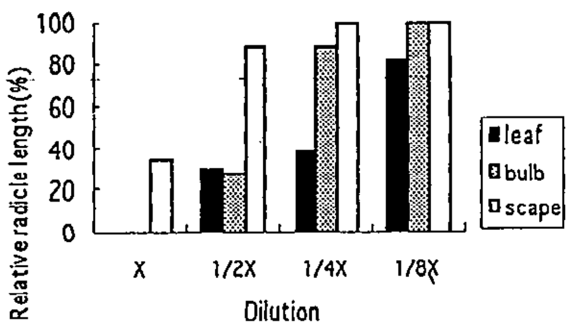


Fig. 1. Effect of water extracts from scaly leaf, scaly bulb and flowering scape on the radicle growth of lettuce in soil.

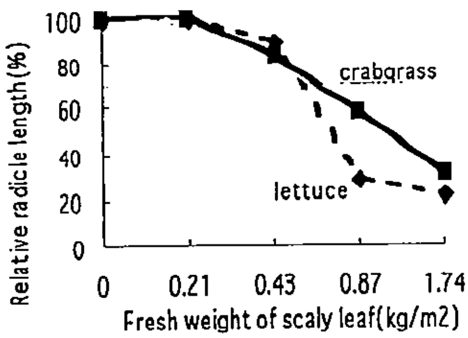


Fig. 2. Relationship between fresh weight of scaly leaf and inhibition of radicle growth of lettuce

Table 1. Relationship between allelopathic activity of three organs in soil and their fresh weight

| | Fresh weight (A) (g/0.25 m$^2$) | Fresh materials for 70% inhibition of radicle growth of lettuce: Fresh weight (B) (g/0.2 5m$^2$) | *B/A* (%) |
|---|---|---|---|
| Scaly bulb | 4167 | 108 | 2.6 |
| Scaly leaf | 1736 | 218 | 12.6 |
| Flowering scape | 1247 | > 435 | 34.9 |

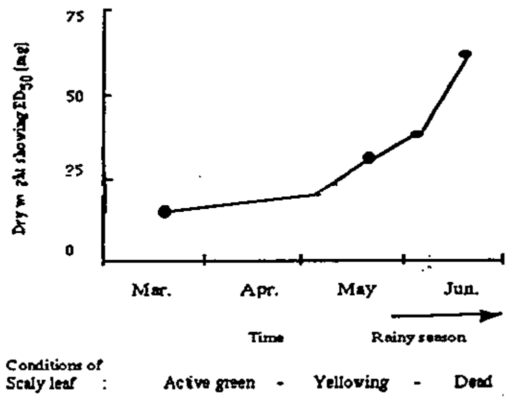


Fig. 3. Seasonal change in allelopathic activity of scaly leaf in its dying period.

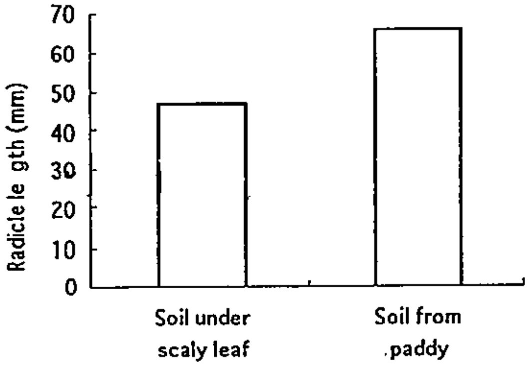


Fig. 4. Radicle growth of lettuce in the field soil take from the areas covered by scaly leaf (June 18).

should. be largely attributed to the release by rain from scaly leaf. In fact, about 30 % inhibition of the radicle growth of lettuce was observed with the soil taken from the area covered by scaly leaves in mid June (Fig. 4).

On the other hand, scaly bulb constantly released allelochemicals into soil whenever the soil was wet (Fig. 5). The amount of those allelochemicals were often enough to inhibit the radicle growth of lettuce. This experiment suggests that scaly bulb may inhibit the emergence of neighbouring annual plants just after rain or under wet conditions. Thus, scaly bulb looks a key organ for allelopathy in *L. radiata* because it exists in the soil in all seasons. This was also

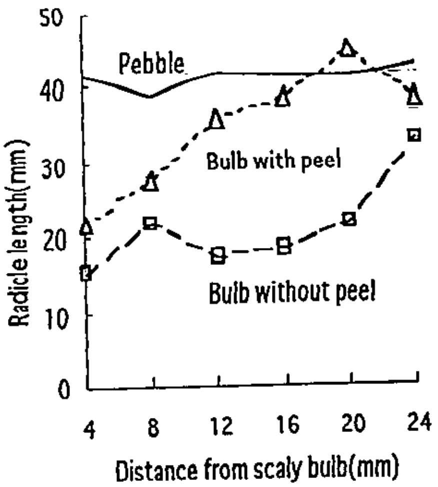


Fig. 5. Effect of allelochemicals released from scaly bulb into soil on the radicle growth of lettuce under wet coinditions.

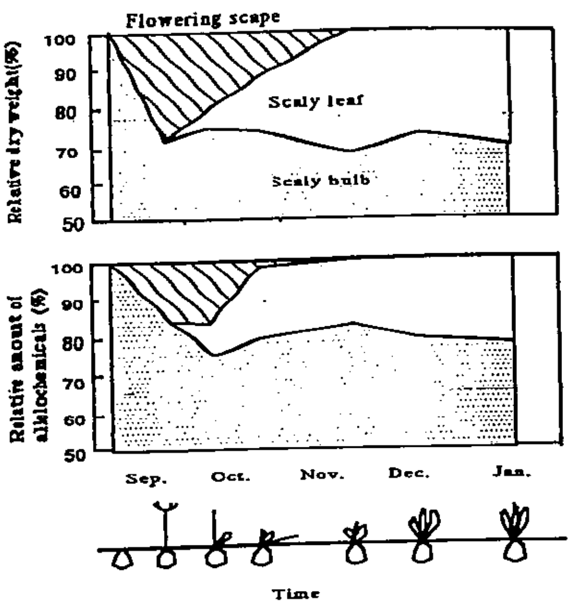


Fig. 6. Seasonal change in allocation patterns of allelochemicals and dry weight in *L. radiata*.

supported by allocation patterns of allelochemicals and dry matter into scaly bulb. Allelochemicals were allocated to scaly bulb more intensively than dry matter (Fig. 6). This was caused by higher allelopathic activity of scaly bulb per dry weight than those of other organs. In addition, actual dry matter of scaly bulb was also higher than others. Therefore, *L. radiata* has desirable allocation patterns of allelochemicals and energy to inhibit the growth of neighbouring plants.

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# ALLELOPATHIC POTENTIAL OF MANILAGRASS [*ZOYSIA MATRELLA* (L.) MERR.]

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*Summary*: Laboratory study was conducted to determine the allelopathic potential of manilagrass. Aqueous extracts of fresh and dried shoots of manilagrass inhibited seed germination and seedling growth of most bioassay species. Dried shoot extracts were more inhibitory than that from fresh shoots to the bioassay species. Inhibitory effects of the shoot extracts differed greatly with the growth stages of manilagrass. The extracts of shoots at vegetative growth stage were more inhibitory on bioassay species than at late vegetative stage. Shoot extracts showed selective toxicity between the assay plants.

*Keywords*: allelopathy, *Zoysia matrella*, manilagrass

## INTRODUCTION

Allelopathy, the direct or indirect effect of one plant on the other plants through the production of chemical compounds that escape into environment, (9) occurs widely in natural plant communities (3) and is postulated to be one mechanism by which crops interfere with weed growth (2, 8). The most obvious and probably the most significant consequence of allelopathy is the control and modification of population densities explaining vegetation patterns in plant communities (7). Allelopathic chemicals released to the environment through decomposition, leaching by water extraction or exudation from living plants and their residues inhibit or stimulate the germination, growth and biomass production of both crops and weed species. Allelopathy is inferred to be of greater importance when vegetation residues are left on the soil surface as compared with annual incorporation of residue into the soil (3, 10). Allelopathy of turfgrasses such as tall fescue, Italian ryegrass, perennial ryegrass, *Cynodon dactylon* (L.) Pers. has been reported (1,4,6). However, no information is available on the allelopathic effects of manilagrass and its residues on the other plants.

The objective of this study was to characterize the potential allelopathic influence of manilagrass in the turfgrass field ecosystem.

## MATERIALS AND METHODS

*Plant harvest, tissue extraction and bioassay seeds*: Manilagrass plants were collected from a turfgrass field at Weed Science Center, Utsunomiya University in August and November in 1995. Water extracts were prepared from the fresh and dried plants. Tissue (100 g) from manilagrass was cut separately into 1-2 cm pieces, added to 1 L of distilled water and kept at 4°C for 48 hours. Dried plants were prepared by air-drying in a greenhouse for 3 days after harvest. Bioassay seeds of crops and weeds were stored for 1-2 years at 10°C before use. These seeds germinated more than 80% in the Petri-dish test.

*Influence of osmotic potential on germination of bioassay species*: Electrical conductivity was used as an indicator to determine the influence of osmotic potential of the plant extracts in the bioassay experiment. Aqueous solutions of K2SO4 and KNO3, and plant tissue extracts were examined for germination inhibition using seeds of livid amaranth, tomato and barnyardgrass (*Echinochloa cruss-galli* (L.) Beauv.).

*Influence of manilagrass extracts on germination of bioassay species*: Twenty seeds each of bioassay species were placed in a separate plastic Petri-dish containing a 5 cm filter paper wetted with 2 ml of test solutions. The covered Petri-dishes were placed in an incubator maintained at 27°C and 80% relative humidity with a 12 h photoperiod. Percent germination and seedling growth data were taken after 7 days. Growth was quantified by measuring the length of radicle and shoot of germinated bioassay species.

*Influence of manilagrass extracts on growth of bioassay species grown in seed pack growth pouch*: Bioassay seeds were placed on a filter paper wetted with distilled water in a Petri-dish and kept in an incubator maintained at 27°C and 80% relative humidity with a 12 h photoperiod. After radicle protrusion, the seedlings were transferred to a seed pack growth pouch moistened with aqueous extracts of the shoots and grown in an incubator under the conditions the same as above. Distilled water was added into the pouches to keep solution volume constant every 3 days. Fourteen days after incubation, plant height and length of roots were measured. All experiments were a RCBD with four replications. The results were subjected to a two-way analysis of variance. Means separated by d.m.r.t. at the 0.05 level of probability.

## RESULTS AND DISCUSSION

*Influence of osmotic potential of aqueous extracts on bioassay species*: A potential artifact that is common to bioassays of plant extracts is the development of solution conditions that are hypertonic to the seed or seedling resulting in physical inhibition of seed germination and plant development. The data indicate that EC higher than 5 mS/cm developed by K2SO4 and KNO3 affected the seed germination and growth of tomato, livid amaranth and barnyardgrass (Table 1). However, the osmotic potential did not greatly influence seed germination and seedling growth of tomato, amaranth and barnyardgrass until EC reached 5 mS/cm. The EC of 10% extracts of fresh and dried shoots of manilagrass harvested in August was less than 5 mS/cm and all extract concentrations used in the experiment were less than 10%. Therefore, osmotic potential was considered to be a non influential factor in the bioassay.

*Comparison of phytotoxicity of extracts from fresh and dried shoots*: In this test, the inhibitory effect of the extracts was larger in tomato than in livid amaranth, and was little in barnyardgrass (Table 2). The extract from dried shoots was more inhibitory than that from fresh shoots to the bioassay species. Germination of tomato, livid amaranth and barnyardgrass was inhibited by 85, 60 and 10%, respectively by the extract from dried shoot (50 mg/ml), and by 75, 45 and 5%, respectively by the extract of the fresh shoots (50 mg/ml). The growth of shoots and roots of these plants were also inhibited more strongly by the extract of dried shoots than that of fresh shoots. The results indicated that, when the shoots were dried, soluble constituents including inhibitors might be easily released from the tissue.

*Comparison of phytotoxicity of extracts from different plant parts*: There were significant differences in inhibitory activity among extracts from different parts of manilagrass (Table 3). Shoot tissue extract exhibited stronger inhibitory activities against livid amaranth at higher concentrations than did root tissue and seed extracts. The results indicate that shoot tissue was the primary source of inhibitors. However at low concentrations, the shoot extract promoted seed germination and seedling growth of livid amaranth. Aqueous extracts from shoots of barley, wheat and rye were also much more inhibitory on assay plants than those from roots (1).

Table 1. Cumulative germination percentage of bioassay species subjected to solutions with the same electric conductivity as the manilagrass leaf extracts.

| EC (mS/cm) | Germination percentage of bioassay species | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Tomato | | | Livid amaranth | | | Barnyardgrass | | |
| | KNO3 | K2SO4 | ME* | KNO3 | K2SO4 | ME | KNO3 | K2SO4 | ME |
| 0 | 100a | 100a | 100a | 100a | 100 | 100a | 100a | 100a | 100a |
| 1 | 100a | 100a | 95a | 100a | 100 | 100a | 100a | 100a | 100a |
| 2 | 100a | 100a | 40b | 100a | 100 | 50b | 100a | 100a | 85ab |
| 4 | 95a | 100a | 0c | 95a | 100 | 5c | 100a | 100a | 75b |
| 6 | 80a | 85a | - | 90a | 90 | - | 95a | 100a | - |
| 8 | 45b | 50b | - | 65b | 80 | - | 75b | 80b | - |
| 10 | 0c | 10c | - | 10c | 15 | - | 45c | 55c | - |

- (*) Manilagrass extracts

Table 2. Effect of aqueous extracts of fresh and dried plant materials of manilagrass on germination and growth of the bioassay species.

| Extracts | Tomato | | | Livid amaranth | | | Barnyardgrass | | |
|---|---|---|---|---|---|---|---|---|---|
| (Conc. mg/ml) | Ger. * | Root * | Shoot* | Ger. | Root | Shoot | Ger. | Root | Shoot |
| Fresh plant | | | | | | | | | |
| 25 | 90a | 100a | 100a | 95a | 85a | 105a | 100a | 95a | 105a |
| 50 | 25b | 90a | 95a | 55b | 60a | 90a | 95a | 80a | 100a |
| 100 | 5c | 45b | 80a | 15c | 30b | 50b | 90a | 70ab | 90a |
| Dried plant | | | | | | | | | |
| 25 | 85a | 100a | 100a | 95a | 70a | 105a | 100a | 80a | 105a |
| 50 | 15b | 60ab | 85a | 40b | 33b | 70ab | 90a | 65b | 90a |
| 100 | 0c | 0c | 0b | 0c | 0c | 0c | 80a | 30c | 65b |

- (*) Ger. = germination percentage, Root = root length, Shoot = shoot length

*Comparison of phytotoxicity of extracts of shoots harvested at different growth stages*: Inhibitory effects of the shoot extracts on bioassay species differed greatly with the growth stages of manilagrass (Table 4). Seed germination of tomato, livid amaranth and crabgrass was inhibited by 87.5, 52.5 and 100%, respectively by that of the shoots (50 mg/ml) harvested in August, and by 33, 0 and 100%, respectively by that of the shoots harvested in early December. Seed germination of crabgrass was inhibited to a lesser extent as compared to the other plants. The results indicate that the extract of shoots at vegetative stage is more inhibitory on tomato and livid amaranth than that at late vegetative stage. Koeppe et al. reported that plant tissues of sunflower at vegetative stages was more inhibitory than those at late stages (5).

*Phytotoxicity of shoot extract to 44 bioassay species*: Inhibitory effect of the extract (50 mg/ml) of the dried shoots harvested in August were tested on seed germination of 44 species (Table 5). Radish, goose grass and chickweed were most sensitive to the inhibition by the extract. Their seed germination was inhibited by 75-100% with the extract. Response of the bioassay species to the extract varied greatly among 44 species. Rice, tomato, Italian ryegrass (Penfine), perennial ryegrass (4 cultivars), tall fescue (3 cultivars) and Japanese lawngrass were sensitive to the extract, and their seed germination was inhibited by 50-75%. Livid amaranth, Italian ryegrass (Harukaze), perennial ryegrass (2 cultivars), centipedegrass, bermudagrass (3 cultivars), kentucky bluegrass and bentgrass were less sensitive. Sorghum, mungbean, cucumber, barnyardgrass, annual bluegrass, crabgrass, Italian ryegrass (5 cultivars) and perennial ryegrass (APM) were rather tolerant. The results demonstrated that the shoot extract showed selectivity between the assay plants. Such a selective action of allelochemicals has also been reported for barley (9).

Table 3. Effect of manilagrass aqueous extracts from different plant part of manilagrass on germination and growth of livid amaranth.

| Conc. (mg/ml) | Germination percentage and seedling growth | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Shoot extracts | | | Stolon extracts | | | Seeds extracts* | | |
| | Ger | Shoot | Root | Ger | Shoot | Root | Ger | Shoot | Root |
| 6.25 | 100b | 100c | 100a | 100b | 100c | 100a | 100b | 100c | 100a |
| 12.5 | 115a | 127.5a | 82.5bcd | 100b | 100c | 100a | 100b | 100c | 100a |
| 25 | 117.5a | 117.5b | 70d | 100b | 100c | 100a | 100b | 100c | 100a |
| 50 | 45d | 85d | 30e | 100b | 100c | 95ab | 100b | 100c | 100a |
| 75 | 15e | 22.5e | 17.5e | 95bc | 95cd | 87.5abc | 95bc | 92.5cd | 90abc |
| 100 | 0f | 0f | 0f | 85c | 85d | 85bc | 85c | 87.5d | 80cd |

- (*) Seeds were harvested in early June in the turf field and stored in a room for 3 months before use.

Table 4. Cumulative percent germination (of control) of bioassay species subjected to aqueous shoots extracts of manilagrass at vegetative and late vegetative growth stage. Control value used here is the cumulative percent seed germination observed following the addition of distilled water.

| Conc. (mg/ml) | Germination percentage of bioassay species | | | | | |
|---|---|---|---|---|---|---|
| | Vegetative shoot extracts* | | | Late vegetative shoot extracts** | | |
| | Tomato | Amaranth | Crabgrass | Tomato | Amaranth | Crabgrass |
| 0 | 100a | 100a | 100a | 100a | 100a | 100a |
| 25 | 78b | 117.5a | 100a | 100a | 110a | 100a |
| 50 | 12.5c | 47.5b | 100a | 67b | 112.5a | 100a |
| 75 | 0d | 15c | 85a | 30c | 98a | 100a |
| 100 | 0d | 0d | 57.5b | 5d | 47.5b | 78b |

* Harvested in August, ** Harvested in early December.

Table 5. Influence of manilagrass shoot aqueous extracts (50 mg/ml) on germination of bioassay species.

| Germination (% of control) | Plant bioassay species |
|---|---|
| 0-25 | radish (*Raphanus sativus*), goosegrass (*Eleusine indica*), chick weed (*Stellaria media*), rice flatsedge (*Cyperus iria*), alsike clover (*Trifolium hybridum*),white clover (*Trifolium repens*). |
| 26-50 | rice (*Oryza sativa*), tomato (*Lycopersicon eculentum*), IR1/ Penfine, PR2/ Common, PR Gator, PR compettitor, PR Emvy, TF3/ Tribute, TF Robel JR, TF Robel 3D, Japanese lawngrass (*Zoysia japonica*) |
| 51-75 | livid amaranth (*Amaranthus lividus*), dandelion (*Taraxacum officinale*), sour paspalum. (*Paspalum conjugatum*), IR Harukaze, PR Giant, PR Juventus, centipedegrass (*Eremochloa ophiuroides*), rmuda4/ Common, Bermuda Cyant, Bermuda Short, Kentucky bluegrass (*Poa pratensis*), bentgrass (*Agrostis palustris*) |
| 76-100 | sorghum (*Sorghum bicolor*), mungbean (*Vigna radiata*), cucumber (*Cucumis sativas* ) barnyardgrass (Echinochloa cruss-galli), annual bluegrass (Poa annua), crabgrass (*Digitaria adscendens*), common purslane (*Portulaca oleracea*), annual sowthistle (*Sonchus oleraceus*), horseweed (*Erigeron canadensis*), IR Common, IR Excellent, IR Top Italian, IR USA, IR Giant, PR APM |

*1/ Lolium multiflorum 2/ Lolium perenne 3/ Festuca arundinace 4/ Cynodon dactylon*

Table 6. Effect of the aqueous extracts of dried shoots of manilagrass on growth of livid amaranth, barnyardgrass and Italian ryegrass grown in seed pack growth pouch for 14 days.

| Concentration (mg DW/ml) | Livid amaranth Shoot* | Livid amaranth Root** | Barnyardgrass Shoot | Barnyardgrass Root | Italian ryegrass Shoot | Italian ryegrass Root |
|---|---|---|---|---|---|---|
| | (cm) | | | | | |
| Control | 2.5a | 2.6a | 8.0a | 5.4a | 7.3a | 6.2a |
| 12.5 | 2.4ab | 2.2ab | 7.4ab | 4.1b | 7.1a | 5.7a |
| 25 | 2.3ab | 1.8b | 7.4ab | 2.0c | 6.6ab | 4.3b |
| 50 | 2.1abc | 0.6c | 7.0ab | 0.8d | 5.7bc | 1.4c |
| 75 | 2.0bc | 0.2d | 6.3bc | 0.7d | 6.3c | 0.2d |
| 100 | 1.7c | 0.1d | 5.8c | 0.1d | 4.6d | 0.1d |

- (*) Shoot = Plant height (*) Root = Length of the longest root

*Influence of manilagrass extracts on growth of bioassay species grown in seed pack growth pouch*: Inhibitory effect of the aqueous extracts of the dried shoots harvested in August was tested on growth of livid amaranth, barnyardgrass and Italian ryegrass (Table 6). The inhibitory effect of the extracts was also larger in livid amaranth than in barnyardgrass and Italian ryegrass in this test. However, growth of barnyardgrass and Italian ryegrass was inhibited at high concentrations of the extracts. Their roots were more sensitive than their shoots to the extracts.

The results of this study provide an evidence that shoot tissue of manilagrass has a significant allelopathic potential and that at least some of the phytotoxins are water soluble. Weed flora and their growth in manilagrass fields may be influenced by shedding of turfgrass, frequent cutting and, in addition allelopathy of manilagrass plants and their residues in thatch layer.

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# ALLELOPATHIC EFFECTS OF WILD SPIKENARD (*HYPTIS SUAVEOLENS* POIT.) ON GROWTH OF RICE SEEDLINGS

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*Summary*: The bio-efficacy of wild spikenard (*Hyptis suaveolens* Poit.) crude extracts was investigated in laboratory studies. Three concentrations of methanol crude extract solution equivalent to 1, 2.5 and 5.0 g of fresh materials, were applied to germinated rice seeds cv. Sew Mae Chan. The longest root and the second leaf sheath length of rice seedlings were measured at 7 days after treatment. The results indicated that wild spikenard extract has allelopathic potential with strong inhibitory effects on rice seedling growth. The growth of roots was inhibited more than the second leaf sheath. The extracts from wild spikenard seeds gave the highest degree of inhibitory effects, while the leaf extracts gave higher degree of inhibitory effects than stem and root extracts.

*Keywords: Hyptis suaveolens*, allelopathic potential, bio-efficacy.

## INTRODUCTION

Wild spikenard (*Hyptis suaveolens* Poit.), an annual herbaceous weed in Labiateae family, is one of the major problem weeds in upland rice, sugarcane fields and other plantations. In Thailand, most of the plants in this family are aromatic plants such as *Ocimum basillicum* L., *O. canum* Sims, *O. gratissimum* L. *O. kirimandcharicum* Guerke. and *O. santum* L. (1). In the field, wild spikenard weed was not attacked by insects. This may be due to aromatic compounds from plant parts aacting as insect repellent. Preliminary studies indicated that wild spikenard contains allelopathic substances (2). In the last 10 years, usage of agricultural pesticides in Thailand increased from year to year ( 3). Recently, it was found that environmental pollution occured with over-use of pesticides. To conserve the environment, botanical pesticides may be adopted for pest control in agriculture, and weeds are of interest as potential sources for natural pesticides. Rice (5) reported that different parts of the same plant contains different levels of inhibitory substances. Studies by Premasthira and Zungsonthiporn (3, 4) also attest that different part of some plant at various growth stages had different inhibitory effects on growth of other plant.

## MATERIALS AND METHODS

Wild spikenard seedlings were planted in 30 cm diameter pots, and 15, 30, 45, 60, 75 and 90 day old plants were collected for phytotoxic investigations on upland rice using seedling bioassay. The whole plant, roots, stems, leaves and seeds of wild spikenard at each collection stage were kept in a freezer as test materials. These materials were extracted with cold methanol as solvent. One hundred grams of each material were homogenized with 50 ml of cold methanol twice by a universal homogenizer (Nippon Seiki, type HC). Filtered methanol extracts of 1.0, 2.5 and 5.0 g equivalents of fresh material were poured into glass vials (30 mm depth x 120 mm height) containing 1.5 g of cellulose powder (Toyo, type D). The vials were dried in a vacuum drier, 4 ml of distilled water were added to each vial and six uniformly germinated rice seeds were placed in each of four replicates. The vials were covered with vinyl film and placed in a growth chamber at a temperature of 30°C with a light intensity of 3,500 lux at plant level. The length of longest root and second leaf sheath of rice seedlings were measured at seven days after treatment.

## RESULTS AND DISCUSSION

The results showed that, the extracts from wild spikenard plants had allelopathic effects on growth of rice seedlings (Table 1). The extracted solution from whole wild spikenard plants inhibited the elongation of root and leaf sheath length of rice seedlings with root growth being inhibited more than leaf sheath when compared to the untreated check. The higher the concentration of the extract solution, the higher the inhibiting effects on rice seedling growth. The maturity of wild spikenard plants also influated the degree of inhibitory effects on indicator plants. Extracts from aged wild spikenard plants had stronger inhibitory effects on rice seedling growth than those from younger plants. The differences in degree of inhibitory effects may be associated with the morphological growth stages of wild spikenard plants. At 7 days after planting the plants were in the early seedling stage with a height about 2 cm, and at 15 days was the seedling stage with young leaf and stem. At 30 days or vegetative stage I, the plants had more leaves and were more developed. At vegetative stage II, at approx. 45 days, leaves and stems were almost fully developed. At 60 days or vegetative stage III, all leaves were fully developed with mature stems. At 75 days, or the flowering stages most of the green leaves turned yellow. At 90 days after planting, was the reproductive stage when seeds matured and leaves started to fall. The results indicated that the inhibitory potential and the concentration of the extractable substances were related to the growth stage of wild spikenard.

The extract from wild spikenard roots, stems, leaves and seeds, had different inhibitory effects on rice seedling growth and the degree of inhibition was also related to the concentration of the solution and the maturity of each plant part. The inhibitory effects of the three concentrations of extracts from each plant part of the same age are shown in Table 2. It was noted that 1.0 g (fresh weight) extract from stems and leaves of 45 and 60 day old spikenard gave higher inhibitory effects on root and second leaf sheath length of rice seedling than those from roots. The root and second leaf sheath length of rice seedlings treated with stem and leaf extracts were shorter than those treated with root extracts of spikenard. The root length of rice seedlings treated with root, stem and leaf extracts of 75 day old spikenard were not significantly different. The extract from seeds of 90 day old spikenard gave higher inhibitory effects on rice seedling growth than those from stem and root extracts. The phytotoxicity to rice seedlings of 2.5 and 5.0 g concentrations of root, stem, leaf and seed extracts of spikenard, produced similar results as the 1.0 g extract concentrations for the respective plant parts. These results indicated that the extracts from leaves of 45, 60 and 75 day old spikenard had stronger inhibition than those of stems and roots, but in the 90 days old spikenard plants, seeds contained the highest level of inhibitory substances.

The effects of spikenard extracts in relation to plant age showed that at the lowest concentration, the effect of extracts from 45-90 days old spikenard roots on rice seedling growth were not significantly different (Table 3). The spikenard stem extracts gave the highest inhibitory effects with 45-60 day old plants. The leaf extracts gave the highest inhibitory effect with leaves from 60 day old plants.

These results indicate that at the vegetative stage of spikenard plants, leaves have higher inhibitory effects than stems and roots because the inhibitory substances were being produced in the leaves which were the main source of metabolic activity (5). At the reproductive stage of spikenard, the seeds act as sink for metabolic products and hence seed extracts gave the highest inhibitory effect on rice seedling growth.

From the above results it may be concluded that spikenard, a troublesome weed in upland fields, contains plant growth inhibiting substances. The effectiveness of these inhibiting substances is depended on the growth stage of plant. At the vegetative stages, the phytotoxic potential of plants in decreasing order were vegetative stage III, II, I and seedling stage. The phytotoxic potential of the plant parts in decreasing order of activity were seeds, leaves, stems and roots.

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Table.1 Effect of extracts of different ages whole spikenard plants on rice seedling growth.

| Days after planting (Age) | Root length (% of control) | | | 2nd leaf sheath length (% of control) | | |
|---|---|---|---|---|---|---|
| | Concentration of extracted substances (fresh weight) | | | | | |
| | 1.0 | 2.5 | 5 | 1 | 2.5 | 5 |
| 7 | 82.74a | 10.36b | 2.26b | 54.89a | 40.98a | 36.62a |
| 15 | 55.07ab | 31.37a | 5.37a | 31.23bc | 35.67a | 32.49b |
| 30 | 56.29ab | 8.31b | 0.29bc | 38.49b | 36.61a | 27.49b |
| 45 | 17.06c | 0.96b | 0.01c | 31.86bc | 33.43ab | 17.82cd |
| 60 | 19.53c | 5.33b | 0.71bc | 22.68bc | 17.12c | 8.49e |
| 75 | 36.53bc | 4.23b | 1.56bc | 23.96bc | 31.78ab | 26.07bc |
| 90 | 11.35c | 8.18b | 0.47bc | 19.03c | 22.68bc | 13.69de |

Values within a column followed by the same letters are not significantly different at 5 % by d.m.r.t.

Table.2 The effects of extracted substances from each of spikenard plant parts on root (R ) and second leaf sheath (S) length ( percent of control) of rice seedlings.

| Part of Spikenard plant | Days after planting(Age) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 45 | | 60 | | 75 | | 90 | |
| | R | S | R | S | R | S | R | S |
| Concentration of extracts 1.0 g fresh weight | | | | | | | | |
| Root | 109.83a | 45.23a | 98.36a | 40.68a | 82.83a | 97.32a | 68.27a | 48.56a |
| Stem | 28.64b | 36.08a | 32.92b | 14.41b | 82.27a | 57.07b | 66.90a | 36.21a |
| Leaf | 43.59b | 18.99b | 11.11b | 20.40ab | 58.26a | 24.01c | - | - |
| Seed | - | - | | - | - | - | 18.92b | 19.39a |
| Concentration of extracts 2.5 g fresh weight | | | | | | | | |
| Root | 10.53a | 42.95a | 7.59a | 34.18a | 27.61a | 34.13a | 10.39a | 34.45a |
| Stem | 7.87ab | 29.19b | 5.97ab | 16.98b | 22.95ab | 23.82a | 15.13a | 29.43a |
| Leaf | 4.26b | 17.55c | 3.60b | 18.75b | 6.67b | 19.90a | - | - |
| Seed | - | - | - | - | - | - | 2.40b | 20.97b |
| Concentration of extracts 5.0 g fresh weight | | | | | | | | |
| Root | 2.61a | 19.91a | 3.14a | 13.87a | 9.45a | 40.12a | 1.83a | 19.89a |
| Stem | 0.37a | 24.64a | 1.26a | 4.71b | 3.56b | 24.16b | 2.74a | 22.16a |
| Leaf | 2.08a | 8.81a | 0.90a | 6.50b | 2.86b | 17.18b | - | - |
| Seed | - | - | - | - | - | - | 1.34a | 11.92b |

Values within a column followed by the same letters are not significantly different at 5 % by d.m.r.t.

Table.3 The effects of extracts of spikenard parts at each growth stage on root (R ) and second leaf sheath (S) length ( percent of control) of rice seedlings.

| Days after planting | Spikenard plant part | | | | | |
|---|---|---|---|---|---|---|
| | Root | | Stem | | Leaves | |
| | R | S | R | S | R | S |
| Concentration of extracts 1.0 g fresh weight | | | | | | |
| 45 | 109.83a | 45.23b | 28.64b | 36.08b | 43.59a | 18.99a |
| 60 | 98.36a | 40.68b | 32.92b | 14.41c | 11.11b | 20.40a |
| 75 | 82.83a | 97.32a | 82.27a | 57.07a | 58.26a | 24.01a |
| 90 | 68.27a | 48.56b | 66.90a | 36.21b | - | - |
| Concentration of extracts 2.5 g of fresh weight | | | | | | |
| 45 | 10.53b | 42.95a | 7.87b | 29.19a | 4.26b | 17.55a |
| 60 | 7.59b | 34.18a | 5.97b | 16.98b | 3.60b | 18.75b |
| 75 | 27.61a | 34.13a | 22.95a | 23.82ab | 6.67a | 19.90a |
| 90 | 10.39b | 34.45a | 15.13ab | 29.43a | - | - |
| Concentration of extracts 5.0 g of fresh weight | | | | | | |
| 45 | 2.61b | 19.19b | 0.37c | 24.64a | 2.08a | 8.81b |
| 60 | 3.14b | 13.87b | 1.26bc | 4.71b | 0.90a | 6.50b |
| 75 | 9.45a | 40.12a | 3.56a | 24.16a | 2.86a | 17.18a |
| 90 | 1.83b | 19.89ab | 2.74ab | 22.16a | - | - |

Values within a column followed by the same letters are not significantly different at 5 % by d.m.r.t.

# ALLELOPATHIC EFFECT OF LEAF RESIDUES AND PARTHENIN EXTRACTED FROM RAGWEED PARTHENIUM ON A FEW TEST CROPS

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*Summary*: Studies were conducted to examine the allelopathic effect of ragweed parthenium on a few crop plants using leaf residues and parthenin (a major sesquiterpene lactone of the weed). Germination and seedling elongation of mung bean, black gram, lentil and chick pea were significantly reduced and were inversely related to the amount of leaf residue added. The phytotoxicity of active component parthenin extracted from the leaves of ragweed parthenium showed a similar germination and growth suppressing trend on the test crop mung bean. Besides, it lowered the total chlorophyll content and water and retarded cellular respiration of one-month old test plant. The study, therefore, suggests that parthenin plays a key function in allelopathic interference of the weed.

*Keywords*: parthenin, ragweed parthenium, allelopathy

## INTRODUCTION

Ragweed Parthenium (*Parthenium hysterophorus* L.) an aggressive noxious weed native to Tropical America has naturalized throughout India and other parts of the world by accidental introduction. It has become a serious medical, agricultural and environmental hazard (8). It invades new areas at a faster rate and reduces the productivity of crops and pastures (1). Most of its environmental and agricultural hazards have been attributed to the phenomenon of allelopathy which refers to any direct or indirect harmful/beneficial effects of one plant on the other through the release of chemical compounds known as allelochemicals (13, 20). Studies have shown that allelochemicals of ragweed parthenium are released as water soluble phyto-inhibitors from leaves, shoots, roots and plant residues (6, 10, 12, 17).

Several sesquiterpene lactones and phenolics known to be involved in the allelopathic interactions have been identified (5, 11, 14). Out of the many sesquiterpene lactones, parthenin is most prevalent and ecologically significant qualitatively as well as quantitatively. Saxena *et al.* (14) isolated and purified parthenin from the ethanol extract of the dried leaf residues of the weed which considerably changed the respiratory activity of germinating mung bean embryos (9). In order to further elucidate its allelopathic effect, the present study was conducted to find out the phytotoxicity of leaf residues on a few pulse crops and parthenin on the germination and physiology of mung bean (*Phaseolus aureus* Roxb. = *Vigna radiata* (L.) R. Wilczek) plants.

## MATERIALS AND METHODS

*Collection of Plant Material*: Seeds of mung bean (*Phaseolus aureus*), black gram (*Phaseolus mungo* L. = *Vigna mungo* (L.) Hepper), lentil (*Lens culinaris* Medikus) and chick pea (*Cicer arientium* L.) were procured from Seed Technology department of Punjab Agricultural University, Ludhiana, India. Fresh and healthy leaves of ragweed parthenium were collected from the locally growing plants.

*Extraction of Parthenin*: The leaves of ragweed parthenium were shade-dried and powdered. Parthenin was extracted from the ethanol extract of the leaf residues following the procedure of Saxena *et al.* (14). Its solutions with concentrations ranging from 0.01 to 0.05% were prepared in distilled water.

*Germination Bioassay*: Powdered leaf residues were added to garden soil at the rate of 1 and 2% in 6" diameter Petri dishes and 20 seeds of test crops (mung bean, black gram, lentil and chick pea) were sown in each Petri dish. Sowing in a set of Petri dishes without leaf residues served as control. The dishes were maintained in a seed germinator at 25±2°C and 75±2% relative humidity and 16 h photoperiod. After ten days, all plants were harvested and germination percentage, and seedling length were determined. Three replicates were maintained for each treatment.

For determining phytotoxicity of parthenin, 50 seeds of mung bean were germinated in the respective concentrations of treatment solution in 6" diameter Petri dishes on a moistened Whatman #1 filter paper underlined with a thin wad of absorbent cotton. The dishes were maintained in a seed germinator at 25±2°C and 75±2% relative humidity and 16 h photoperiod. Daily counts of germinated seeds were made and after seven days final germination record was made and seedling length was measured.

*Treatment of mature mung bean plant.* One month old mung bean plants raised in earthenware pots (3 plants per pot) were spray treated with different concentrations of parthenin or water (as control) for three consecutive evenings. On the following morning, the leaves of treated plants excised, extracted with DMSO as per Hiscox and Israelstam (4) and total chlorophyll content estimated. as per Daizy and Kohli (3), and Cell respiration - a measure of cell survival was determined as per Steponkus and Lanphear (16). The water content was measured using Dean and Stark apparatus (18). For each treatment three replicates were maintained in a completely randomized block.

*Statistical Analysis.* The data were analyzed using one-way anova and Duncan's multiple range test (15).

## RESULTS AND DISCUSSION

The results indicate that germination of test crops *viz.* mung bean, black gram, lentil and chick pea was significantly inhibited in soil mixed with leaf residues of ragweed parthenium (Table 1). The effect was more apparent when 2 g leaf residue was incorporated into the soil and maximum reduction in germination was observed in mung bean where only 10% seeds germinated. Likewise, seedling growth was appreciably reduced by ragweed parthenium leaf residues, with more than 50% reduction in all test crops in the 1% mixture, except black gram (Table 1).

Table 1. Effect of soil incorporated ragweed parthenium leaf residues on the germination and seedling growth of test crops.

| Test Plant | Amount of leaf residues g/100g soil | Germination (%) | Seedling length (cm) |
|---|---|---|---|
| Mung Bean | 0 | $95^a$ | 6.52±2.79 |
| | 1 | $35^b$ | 2.94±0.81 |
| | 2 | $10^c$ | 1.80±0.74 |
| Black Gram | 0 | $100^a$ | 7.27±1.92 |
| | 1 | $75^b$ | 6.52±1.09 |
| | 2 | $65^c$ | 1.89±0.62 |
| Lentil | 0 | $100^a$ | 15.21±3.78 |
| | 1 | $70^b$ | 3.53±1.68 |
| | 2 | $40^c$ | 1.91±0.56 |
| Chick Pea | 0 | $90^a$ | 24.47±4.08 |
| | 1 | $60^b$ | 14.87±3.36 |
| | 2 | $35^c$ | 2.89±0.58 |

Similar superscripts in a column represent insignificant difference at 5 % level applying d.m.r.t..
± represents s.e.

Parthenin extracted from leaf residues also exhibited phytotoxicity against mung bean as indicated by its effect on the germination (Table 2). At the lower concentrations of 0.01 and 0.02% parthenin germination remained unaffected, whereas seedling growth was appreciably reduced. At higher concentrations of 0.03 and 0.04% parthenin germination and seedling growth were significantly reduced. However, at the highest concentration of 0.05% parthenin none of the seeds germinated showing a complete inhibition (Table 2). In other words, there was an inverse relationship between concentration of parthenin and germination.

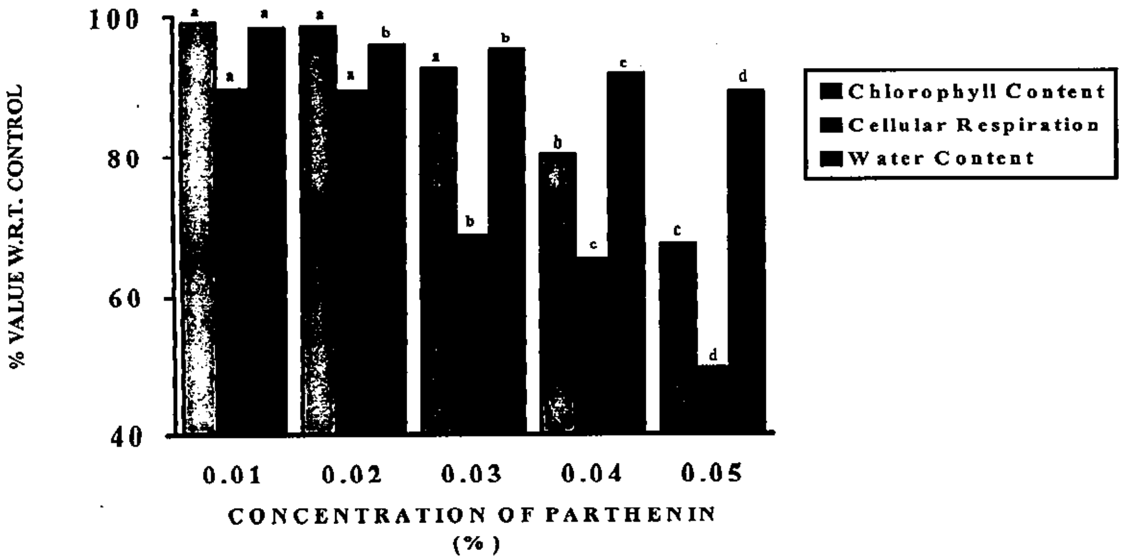
Table 2. Effect of different concentrations of Parthenin on germination and seedling growth of mung bean

| Concentration of Parthenin (%) | Germination (%) | Seedling length (cm) |
|---|---|---|
| 0 | 100[a] | 13.75[a] |
| 0.01 | 100[a] | 9.83[b] |
| 0.02 | 100[a] | 5.92[c] |
| 0.03 | 40[b] | * |
| 0.04 | 10[c] | * |
| 0.05 | 0 | - |

*Not measurable
Same superscripts in a column represent no significant difference at 5 % level by d.m.r.t.

The total chlorophyll content, cellular respiration and water content in leaves of one-month old mung bean plants were also reduced in response to different concentrations of parthenin (Fig. 1). With increasing concentration of parthenin, a further decrease was noticed showing a dose-response relationship. The effect was more apparent at 0.03% or higher concentrations of parthenin (Fig. 1).

Figure 1. Effect of different concentrations of Parthenin on total chlorophyll content, cellular respiration and water content of mung bean.




Different symbols above bars in a parameter represent significant difference at 5% level applying Duncan's multiple range test.

It is clear from the present study that ragweed parthenium exerts phytotoxicity/allelopathic effects through its leaf residues and the active parthenin component significantly inhibited germination and seedling growth of test crops. The effect progressively increased with increasing amount of leaf residues or parthenin. Similar decrease in seedling emergence has been reported in case of cotton and pitted morning glory in response to increasing amount of crimson clover and hairy vetch residues incorporated in soil (19). Likewise, the growth of a number of test species was significantly decreased with incorporation of wormwood residues and the effect was inversely related to the amount incorporated (21).

In addition to germination, the chlorophyll content, cellular respiration and water content of mature mung bean plants treated with parthenin were also reduced. The study, therefore, establishes that parthenin plays a key role in imparting allelopathic property to the weed. Because of this property ragweed parthenium has an ecological advantage over other crop and pasture plants and thus exhibits strong interference in natural and agroecosystems. Parthenin - a sesquiterpene lactone, has also been reported to be autotoxic to the germination of the parent plant, thus self-regulating itself (11). However, once the germination has occurred ragweed parthenium plants do not affect each other and promote their own territory and eliminate other flora by the release of phytotoxic allelochemicals (7). Besides being allelopathic /phytotoxic, parthenin is also responsible for a number of properties of the weed (8) including growth regulatory activities comparable to auxins (2). The chemical parthenin, therefore needs to be carefully examined/tested so as to exploit its allelopathic and phytotoxic properties, particularly for the management of the other noxious weeds.

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DODDER MANAGEMENT IN VEGETABLES IN THE MIDDLE EAST

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*Summary:* Experiments were conducted to study the efficacy of several herbicides for the control of dodder (*Cuscuta campestris*) on some vegetable crops. It was found that post-attachment application of glufosinate ammonium at 25 ppm (a.i.) v/v, sprayed on mint (*Mentha piperita*) at a volume of 100 ml/m$^2$, gave good selective control of dodder. In the same trial glufosinate at 50 ppm and above were toxic to mint as was glyphosate at 100 ppm (a.i.) and above. Chard, (*Beta vulgaris* L. var. *Cicla*), red beet (*Beta vulgaris* L.) and radish (*Raphanus sativus* L.) were tolerant to 25-50 ppm glufosinate, and to 75-100 ppm glyphosate. In the case of tomato (*Lycopersicum esculentum*) glyphosate at 25-75 ppm controlled dodder, but caused some phytotoxicity to the crop. However, the application of glyphosate at 25 ppm controlled the parasite without apparent phytotoxicity to mallow (*Corchorus olitorus*). It is recommended to study the response of other economically grown vegetable crops in the region to herbicide treatments which proved effective in the control of dodder. Herbicide residues in the treated crops, however, should also be investigated.

*Keywords:* olericulture, parasitic weed, *Cuscuta*

## INTRODUCTION

Dodder is a stem and leaf parasite which twines on several vegetable and forage crops, fruit trees and desert shrubs, ornamental plants and weeds in the Middle East. It is especially detrimental to alfalfa (*Medicago sativa*) (5), Jew's mallow, mint, tomato, turnip, (*Brassica rapa*) and wild jasmine (*Clerodendron inerme*) (15). The light soils and hot climate of the Middle East favour the germination of dodder seed, and the spread and twining of its shoots on the foliage of host plants. Under heavy infestation of dodder, vegetable crops may be completely destroyed.

Several soil-applied herbicides have been reported to control dodder selectively in alfalia (4, 8, 9, 11) and some pulse crops (14, 16). Orloff and Cudney (13) showed that the combination of pre-emergence treatment of trifluralin followed by mowing and burning result in good control of dodder in alfalfa. Mycoherbicides gave excellent control of dodder in mint and other vegetables which showed no susceptibility to the fungi inoculum (3). Non-selective contact herbicides control dodder after its attachment to host plants (6, 10), however, these chemicals destroy both the parasite and the host. Glyphosate at very low doses was found to control attached dodder selectively in tomato and alfalfa (7). It also controlled *C. monogyna* Vahl on citrus (*Citrus sinensis*) (1) at rates of 50 ppm, and C. *campestris* Yuncker on Jew's mallow at 25 ppm (2). Nemli (12) reported on the resistance of some crops to dodder. The objective of this study was to evaluate the efficacy of certain herbicides for the selective control of attached dodder on some vegetable crops in the United Arab Emirates (U.A.E).

## MATERIALS AND METHODS

*Pot experiment I on five vegetables:* In order to study the response of several economically-grown vegetable crops to herbicide treatments which proved effective in the control of dodder in mint in a preliminary experiment (15), five local cultivars of chard, spinach (*Spinacia oleracea*) turnip, radish and red beet were grown in 25 cm pots in the greenhouse at the Faculty Farm of U.A.E. University in Al-Oha under *Cuscuta*-free conditions. When the seedlings reached about 15 cm high, two rates each of glufosinate at 25 and 50 ppm and glyphosate at 75 and 100 ppm which were effective on mint were sprayed on the foliage of the vegetable crops. The spray volume used was 100 ml/m$^2$. The treatments and the control pots, sprayed with water, were replicated 4x in the randomized complete block design. One week after spraying, visual rating of herbicide injury was made using a scale of 0 (no effect) to 10 (severe phytotoxicity). Shoot fresh weight was measured three weeks after herbicide application, and data were expressed as to percent of the untreated control. The results were analyzed using Duncan's Multiple Range Test.

*Pot experiment II on three vegetables:* Local cultivars of vegetable crops which tolerated effective herbicide treatments in Experiment I were grown in 25 cm pots in the greenhouse at the Faculty Farm in Al-Oha. These were chard, turnip and redbeets. When the seedlings reached about 10 cm high, they were infested with C. *campestris* tendrils by placing them around the stems and leaves of these vegetables. After the tendrils of dodder had twined and attached to the hosts, and the crop reached about 15 cm high, two rates of glufosinate at 25 and 50 ppm and glyphosate at 75 and 100 ppm were sprayed on the foliage of the infested vegetable crops. The spray volume used was 100 ml/m. The treatments and control pots sprayed with water, were replicated 5x in a randomized complete block design. One and three weeks after spraying, visual rating of herbicide injury was made on both the hosts and the parasite using a scale of 0 (no effect) to 10 (severe phytotoxicity). Shoot fresh weight of vegetables was measured three weeks after herbicide application, and data were expressed as percent of untreated control. The results were analyzed using Duncan's Multiple Range Test.

*Field experimemnt on Jew's mallow:* A field of Jew's mallow infested with dodder was sprayed with glufosinate at 0,80, 100, 120, 140 and 160 ppm in Ghummaid/Sweihan area in Abu-Dhabi Emirate, U.A.E. Plots were 1 $m^2$ and the spray volume was 100 ml/$m^2$, with control plots sprayed with water. The experiment was replicated 3x in randomized complete blocks. Vigor of the crop and parasite were evaluated visually two weeks after herbicide application.

## RESULTS AND DISCUSSION

*Pot experiment I:* Data in Table 1 show that glufosinate, specially at 50 ppm, caused 75-85% phytotoxicity to all vegetable crops one week after treatment. However, phytotoxic symptoms were minimized two weeks later in the case of radish and turnip which had shoot fresh weights of 70-80% relative to untreated control. In the case of glyphosate, phytotoxicity was around 25-35% one week after application in all vegetable crops and increased to around 40-50% as indicated by the shoot fresh weight two weeks later, with the exception of beets which were normal and not significantly different from the untreated control.

Table 1. Tolerance of some vegetable crops to herbicide treatments effective in dodder control[1].

| Treatments (ppm)[2] | | Crops | Visual rating[3] | Shoot fresh weight | |
|---|---|---|---|---|---|
| | | | | (gm/pot) | (% of control) |
| Glufosinate | 25 | Radish | 7.5 c | 85.7 ab | 70.1 |
| | 50 | | 7.5 c | 78.3 b | 64.0 |
| Glyphosate | 75 | | 3.0 b | 67.1 b | 57.9 |
| | 100 | | 2.5 b | 69.8 b | 57.1 |
| Control ($H_2O$) | non-infested | | 0.0 a | 122.3 a | 100.0 |
| Glufosinate | 25 | Turnip | 8.5 c | 137.4 ab | 71.2 |
| | 50 | | 8.5 c | 156.0 ab | 80.8 |
| Glyphosate | 75 | | 4.3 b | 94.8 b | 49.1 |
| | 100 | | 3.5 ab | 86.3 b | 44.7 |
| Control ($H_2O$) | non-infested | | 1.0 a | 193.1 a | 100.0 |
| Glufosinate | 25 | Spinach | 3.5 c | 47.8 ab | 77.8 |
| | 50 | | 8.0 d | 13.8 b | 22.5 |
| Glyphosate | 75 | | 1.0 ab | 34.6 ab | 56.3 |
| | 100 | | 2.5 bc | 11.5 b | 18.7 |
| Control ($H_2O$) | non-infested | | 0.0 a | 61.4 a | 100.0 |
| Glufosinate | 25 | Chard | 6.0 c | 88.8 ab | 56.3 |
| | 50 | | 7.5 c | 58.1 b | 36.9 |
| Glyphosate | 75 | | 3.5 b | 89.5 ab | 56.8 |
| | 100 | | 2.0 ab | 100.4 ab | 63.7 |
| Control ($H_2O$) | non-infested | | 1.0 a | 157.6 a | 100.0 |
| Glusofinate | 25 | Beets | 7.5 c | 7.8 b | 26.1 |
| | 50 | | 8.5 c | 7.3 b | 19.4 |
| Glyphosate | 75 | | 3.0 b | 47.1 a | 125.3 |
| | 100 | | 3.0 b | 36.5 a | 97.1 |
| Control ($H_2O$) | non-infested | | 1.0 a | 37.6 a | 100.0 |

[1] Means followed by the same letter in beets column and crop are not significantly different at the 5% level of probability (Duncan's multiple range test).
[2] Spraying date: 12.4.93
[3] No effect = 0; severe phototoxicity = 10.

*Pot experiment II:* Turnip was severely infested with a leaf-feeding insect which weakened the crop and did not allow the dodder to parasitize it adequately. In the case of beets, dodder was killed in all infested treatments including the control due to lack of parasitism. Data in Table 2 show that glufosinate and glyphosate at high rates tested gave about

50-55% phytotoxicity in turnip and 15-30% phytotoxicity in beets, respectively, whereas dodder control did not exceed 44% in the case of turnip which supported parasitism.

Table 2: Tolerance of turnip and red beets to herbicide treatments effective in dodder control[1].

| Treatments (ppm)[2] | | Visual rating[3] | | | |
|---|---|---|---|---|---|
| | | Turnip | Dodder | Beets | Dodder |
| Glufosinate | 25 | 3.2 b | 3.0 b | 3.4 a | 10.0 a |
| | 50 | 5.0 a | 4.4 a | 3.4 a | 10.0 a |
| Glyphosate | 75 | 2.0 c | 3.2 b | 0.2 d | 10.0 a |
| | 100 | 5.6 a | 4.4 a | 1.4 c | 10.0 a |
| Control ($H_2O$) | infested | 3.6 b | 0.2 c | 2.6 b | 10.0 a |
| ($H_2O$) | non-infested | 3.0 b | --- | 2.6 b | --- |

[1] Means followed by the same letter in each column are not significantly different at the 5% level of probability (Duncan's multiple range test).

[2] Spraying date: 18.5.94.

[3] No effect = 0; severe phytotoxicity = 10 (25.5.94).

In the case of chard, glufosinate at 50 ppm caused some yellowing and scorching of the foliage, however, the fresh weight recorded 3 weeks after spraying was not significantly different from the controls, and dodder control was low. On the other hand, glyphosate at 100 ppm gave 96% dodder control with shoot fresh weight which exceeded that of the controls (Table 3).

Table 3: Effect of herbicides on dodder control in chard[1].

| Treatments (ppm)(2) | | Visual rating(3) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Chard 11.5.94 | 25.5.94 | Dodder 11.5.94 | 25.4.94 | Shoot fresh (gm/pot) | weight (% of control) |
| Clufosinate | 25 | 0.0 b | 2.6 b | 0.0 c | 1.4 d | 196.4 b | 106.7 |
| | 50 | 2.8 a | 4.4 a | 0.8 b | 3.4 c | 199.3 b | 108.2 |
| Glyphosate | 75 | 0.0 b | 1.4 d | 1.2 b | 6.4 b | 222.2 a | 120.7 |
| | 100 | 0.2 b | 2.0 c | 3.0 a | 9.6 a | 240.5 a | 130.6 |
| Control ($H_2O$) | infested | 0.0b | 1.4d | 0.0c | 0.0e | 184.1b | 100.0 |
| Control ($H_2O$) | non-infested | 0.0 b | 2.2 bc | - | - | 181.1 b | 98.3 |

(1) Means followed by the same letter in each column are not significantly different at the 5% level of phytoxicity (Duncan's multiple range test).

(2) Spraying date: 4.5.94.

(3) No effect = 0; severe phytoxicity = 10.

*Jew's mallow:* It was observed that glufosinate at all concentrations tested controlled dodder. However, the crop did not tolerate the herbicide which caused 100% phytotoxicity (unpublished data).

*General discussion and conclusions:* It may be concluded that glufosinate caused 50% phytotoxicity to turnip and 44% dodder control. In beets injury was minimal and parasitism did not hold, however, at 80-160 ppm the herbicide was not phytotoxic to beets and chard. Glyphosate at 100 pm gave 96% dodder control and excellent yield of chard leaves.

It is recommended that lower concentrations of the herbicides tested as well as others such as chlorsulfuron and imidazolinones be evaluated in the future for selective dodder control in vegetable crops. However, preventive methods such as planting of uncontamined crop seeds, and enforcing strict quarantine laws against the introduction of *Cuscuta* spp. may ensure a successful dodder management program in the Middle East.

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# RICE HERBICIDES AND WATER QUALITY: A CALIFORNIA SUCCESS STORY IN GOVERNMENT AND INDUSTRY COORDINATION

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*Summary:* Traditional irrigation practices allowed herbicide-treated tailwaters to move downstream from California rice (*Oryza sativa*, L.) farms. Amid public concern over environmental pollution from rice herbicides, the Rice Pesticide Workgroup (RPW) was formed to establish policy to mitigate the environmental impact of rice herbicides without economic harm to rice producers. This case study looks at the RPW's success with two rice herbicides: molinate and thiobencarb. Through the coordinated use of water holding periods, monitoring of public waterways, and education to change rice cultural practices, mass loading of molinate in the Sacramento River was reduced from 18,465 kg in 1982 to 84 kg in 1995. Mass loading of thiobencarb was reduced from 2,317 kg in 1985 to non-detectable levels since 1991. Current seasonal peaks (1996) of molinate and thiobencarb in the Sacramento River are less than 1 part per billion (ppb).

*Keywords*: rice, water quality, molinate, thiobencarb, environment.

## INTRODUCTION

During a five year period from 1977 to 1982 the use of molinate and thiobencarb to control watergrass, *Echinochloa spp.*, more than tripled in California rice. Following short water holding periods for rice herbicides, irrigation waters were allowed to flow continuously through the system and off the farm as a means of managing water depth for seedling establishment. Rice pesticides, generally applied early in the season to flooded fields, were discharged to large surface drains which flowed into the Sacramento River and its tributaries and thence to the California Delta. By 1982, molinate was found to be responsible for tens of thousands of carp (*Cyprinus carpio*) kills and a metabolite of thiobencarb was identified as the agent behind drinking water taste complaints in the City of Sacramento.

## EARLY SOLUTIONS

Although the causes of carp kills and taste complaints were identified by 1982, mitigation of rice pesticide problems required a cooperative effort on the part of regulatory agencies, the University of California Cooperative Extension and the rice industry. The charge of this diverse group, allied as the Rice Pesticide Workgroup (Table 1), would be to:

- Identify concentrations which might adversely affect water quality with respect to human health and aquatic biota.
- Suggest Maximum Contaminant Levels (MCL's).
- Identify the kinetics of dissipation and the environmental fate of rice pesticides.
- Develop criteria and set water quality goals (performance goals) reflective of the MCL's; for public waterways.
- Identify best management practices (BMP's) to reduce the environmental impact of rice pesticides while maintaining productivity.
- Phase in BMP's to allow rice producers to adjust to problems associated with new practices.
- Create demonstration and conservation programs for educational, technical and cost share assistance to reduce economic impacts of BMP's and to overcome barriers to adoption.
- Monitor pesticides in public waterways and create a response program in the event performance goals were exceeded.

Establishing numerical guidelines for environmental protection and acceptable Maximum Concentration Levels (MCL's) for the Sacramento River fell to two regulatory agencies: the Department of Health Services and the Department of Fish and Game. Permissible daily intake concentrations were calculated as 1/100 of the 'No Observable Effect Level' (NOEL) as determined by rat and dog studies (5).

The MCL's for molinate and thiobencarb were established at 20 mg/L (20 ppb) and 70 mg/L (70 ppb), respectively. However, MCL's for thiobencarb at 1 mg/L (1 ppb) to protect the taste of Sacramento City's drinking water supply. These MCL's were defined by the Rice Pesticide Workgroup as 'performance goals' for the rice industry. If concentrations of rice pesticides exceeded the performance goals for the Sacramento River, regulatory actions could include the cancellation of the two principal herbicides molinate and thiobencarb, leaving the industry little opportunity to adjust cultural practices to the new laws.

Table 1. The Rice Pesticide Workgroup (RPW)

| Regulatory | Technology and Extension |
|---|---|
| Regional Water Quality Control Board-Central Valley | University of California Cooperative Extension |
| California Department of Food and Agriculture | City of Sacramento |
| California Department of Fish and Game | Rice Industry |
| Department of Health Services | Rice Research Board |
| County Agriculture Commissioners | Rice Producers |

To meet the performance goals, the RPW established 'holding periods', defined as a period of time after an herbicide application during which no water could be released from the field. The purpose of the holding time was to allow herbicides to degrade or dissipate on-site.

Molinate breakdown occurs at a half-life of approximately 2 to 5 days in rice fields, whereas thiobencarb was found to have a half-life of 6 to 10 days (6, 7, 8, 9). In addition, thiobencarb is relatively insoluble in water, leaving a relatively large proportion in the soil to re-enter the ricefield water. Thus, different strategies were recommended by the RPW for managing the two compounds.

To meet the molinate performance goal of 20 ppb, the holding period was first established at 8 days in 1984, doubling the manufacturers label requirement of a 4-day hold for efficacy. The holding periods were gradually increased to 24 days by 1991 (Fig. 1). This phase-in of longer holding periods allowed rice-producers to adopt water management practices for long early-season holds. Rice farmers' primary concern was increased risk to stand establishment. Although continuous flooding is a standard California practice, farmers had previously had the option to drain fields to enhance seedling growth where vigor was poor. To mitigate this concern, the RPW solutions allowed emergency releases during the holding period in the event of demonstrated potential for economic damage to individual producers.

Local Agricultural Commissioners were responsible for regulating pesticide applications, insuring that growers complied with holding periods, and administering fines when necessary. The California Department of Food and Agriculture was charged with monitoring public waterways to insure that performance goals were met. The University of California provided education and research related to improved irrigation methods, holding periods and their positive impact on downstream water quality, and the adverse political and regulatory impacts to the industry of exceeding the performance goals. These activities prevented molinate concentrations from substantially exceeding the performance goals during the initial phase-in of the program.

The persistence of thiobencarb in the soil and water, however, required an altogether different solution to meet the 1 mg/L MCL. In addition to a 6-30 day water holding period on thiobencarb, sales of the herbicide were voluntarily limited to the amount of product required for 40500 ha, or about 25% of the rice acreage.

## MID- AND LONG-TERM SOLUTIONS

By 1992, and thereafter, rice producers faced a barrage of compliance concerns. In 1992, for example, the water holding period for molinate was set at 28 days after application and the performance goal was lowered to 10 ppb in public waterways. Concurrent with longer holds and lower performance goals, planted area increased by 30% from 1991 to 1996, with a concomitant loss of fallow land which many growers had used to pond ricefield tailwaters, thus complying with regulations. Additionally in 1995, emergency releases were no longer allowed.

Growers initially complied with holding periods by simply blocking outlets and risking deep water and stand establishment problems in lower basins. However, as holding periods increased and less area was available for ponding, some producers, as well as entire water districts, began to experiment with systems that would allow recapture and re-use of tailwater to contain pesticides.

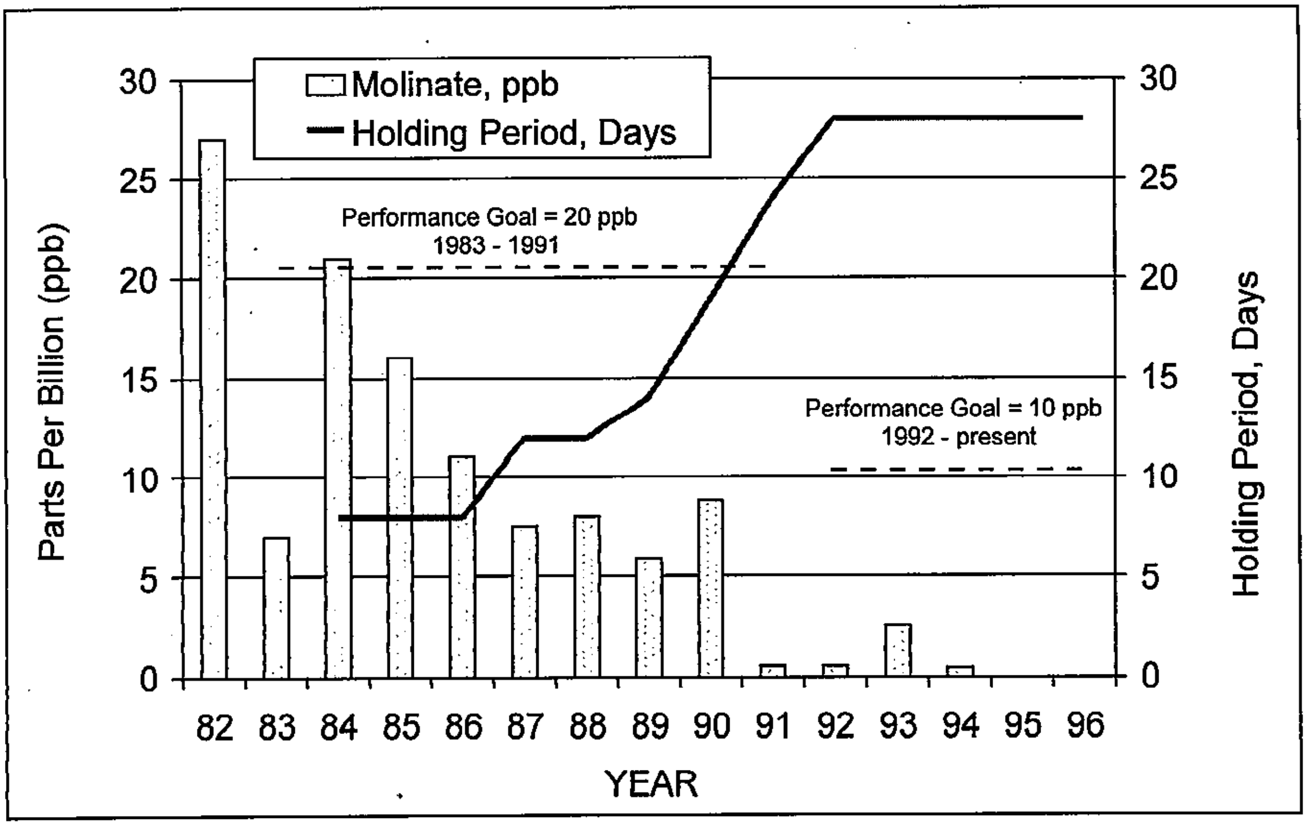


Figure 1. A phase-in of holding periods allowed rice producers to adjust to changing cultural practices. From the beginning of the rice pesticide program, peak concentrations of rice pesticides never substantially exceeded performance goals. Prior to 1984 molinate was held on field for 4 days for efficacy.

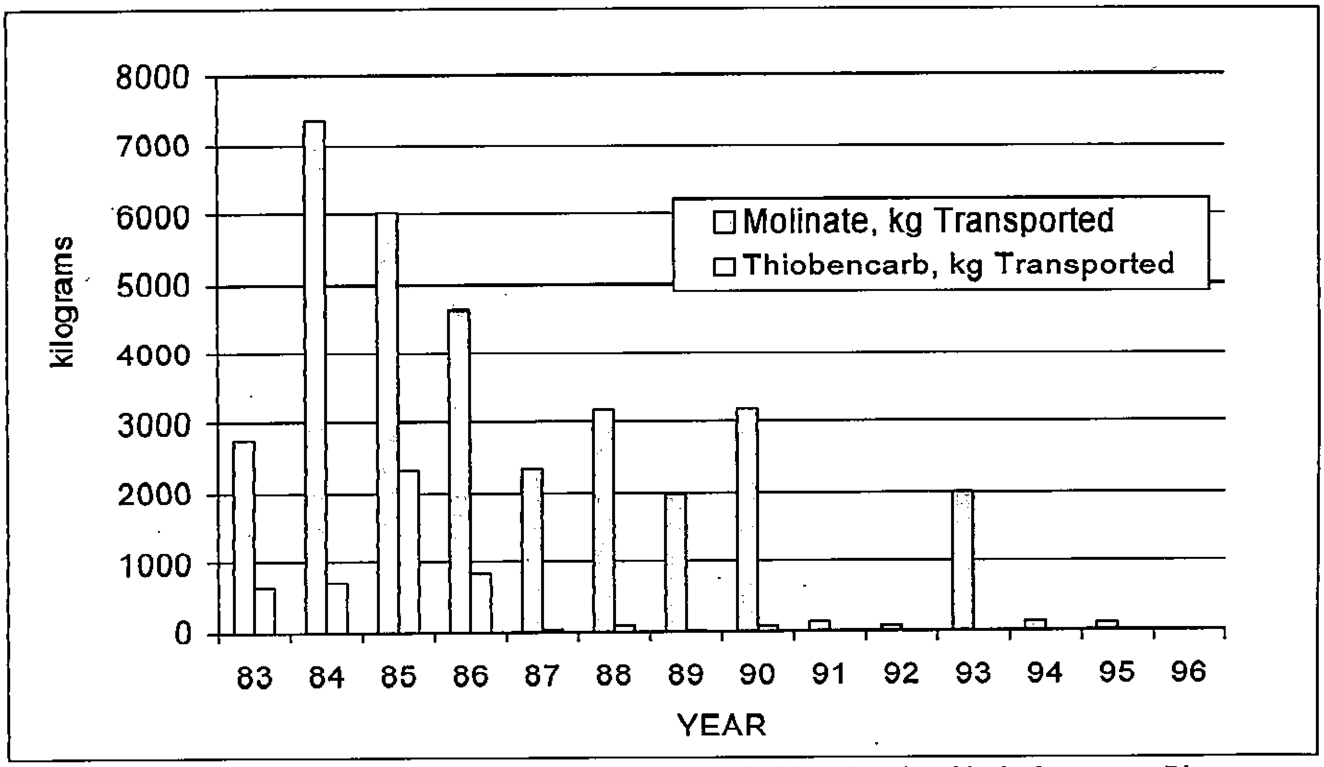


Figure 2. Mass loading of both molinate and thiobencarb have been significantly reduced in the Sacramento River over the life of the program.

Recirculation was the most commonly used management system to recapture polluted tailwater in a sump or basin at the lower end of the farm or district and pump it to highline ditches for reuse. Static systems were also designed for individual basin control providing little opportunity for accidental spillage. A few growers experimented with `good neighbor systems' in which herbicide treated waters were moved from field to field and farm to farm, bypassing ditches and canals, by means of drop pipes (3, 4).

To assist rice producers, Cooperative Extension, in collaboration with federal technical and cost-share agencies, established two large-scale demonstration farms to compare traditional flow-through, recalculating and static systems. The demonstration farms operated for 5 years and served as educational flagships for farmer education, as well as for research on the fate of herbicides in the rice environment, water use, and crop growth and yield.

Several agencies provided help to California rice farmers during the program. The University of California provided extensive farmer education programs and the Natural Resource Conservation Service offered technical and engineering design of improved irrigation systems. Partial funding for farmers to build systems came through three different programs: the USDA Farm Service Agency's Agricultural Conservation Practices program; the Zeneca/California Rice Industry Association Water Recovery program; and the Pacific Gas and Electric energy savings program. The combination of educational, technical and cost-share assistance programs were designed to overcome barriers to the adoption of water recovery systems, depending on the needs of individual producers. Over US$600,000 in cost share assistance was distributed for closed systems.

## RESULTS--GROWER ADOPTION

Monitoring concentrations and mass loading of rice pesticides in the Sacramento River at the City of Sacramento's drinking water supply intake was one of the most crucial measures of the success of the RPW. Peak concentrations of molinate dropped from 27 ppb prior to the water holding program in 1982 to non-detectable levels (<1ppb) in 1994 through 1996 (Fig. 1) (2). Mass loading of molinate dropped from 18,464 kg in 1982 to an estimated 84 kg in 1995 (Fig. 2). Similarly, thiobencarb concentrations dropped from a high of 6 ppb in 1982 to less than 1 ppb in 1991 through 1996. Mass loading of thiobencarb dropped from a high of 2,318 kg in 1985 to 0 kg by 1991 (Fig. 2).

A six-year, four-county tracking study followed adoption of tailwater management systems. In the six year period from 1991 to 1996, the area in closed systems increased from about 30,500 ha to 70,000 ha accounting for about 40% of the four-county total rice acreage (1). On a state-wide basis, area in permanent closed systems is now estimated to be 50% of the total ha.

## FUTURE ISSUES: WHERE DO WE GO FROM HERE?

California's tough regulatory environment requires continued innovation on the part of rice farmers to find new solutions to continually improve irrigation systems. Recent regional plans have defined agricultural drains as `coincidental aquatic habitat', requiring protection against further degradation. Interpretation of these plans will be critical to determine where these new rules will be applied. As such, performance goals could be applied to drains at rice field outlets. In many large agricultural drains, unlike in the Sacramento River, molinate and thiobencarb concentrations have exceeded the established performance goals. Thus far, performance goals have been applied only to natural bodies of water, but not to farmer constructed waterways. Hence, potentially contentious debate looms on the horizon to establish where such performance goals will be applied. Nonetheless, substantial improvement to rice irrigation systems has reduced herbicide runoff by over 98% in the past decade.

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# PRACTICAL ASPECTS OF PESTICIDE MODELLING FOR ENVIRONMENTAL-RISK ASSESSMENT

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*Summary*: Practical aspects of pesticide modelling for environmental risk are illustrated using models that simulate the leaching and degradation of herbicides in soils.

*Keywords*: simulation, decision-support system, herbicide

## INTRODUCTION

It is impossible to experimentally determine the fate in the environment for all combinations of compounds, soils, weather patterns, crops and timings. Simulation models, calibrated or validated on a limited range of experimental data-sets, can be used to make predictions of fate in the environment for a wider range of untested conditions. Therefore, there are opportunities to use simulations as an economical substitute for field and laboratory experiments. Some of the challenges and opportunities provided by different modelling approaches are illustrated by the simulation of leaching and degradation of herbicides in soils.

## MECHANISTIC AND EMPIRICAL MODELLING

An initial approach to modelling is to take the best scientific laws that are appropriate and combine them in a computer program to simulate the phenomenon of interest. The first model widely available in Europe that simulated leaching of pesticides in soil was that of Leistra (6). This model has been further developed and is now known as PESTLA (1). Input data required for PESTLA include soil hydraulic conductivities and soil-water potential as functions of depth and soil-water content, soil bulk density, diffusion coefficients, tortuosities of diffusion and dispersion lengths. Two Freundlich sorption coefficients and the rate of degradation of the pesticide at a fixed temperature and soil-water content are further needed. Much of the soil physical data is difficult to measure and sensitive to many variables and is probably only obtainable from institutions with an established soil-physics discipline. Nonetheless, this type of model gives useful simulations of pesticide distributions in the upper layers of soils. The model can be soundly justified because it is based on established scientific laws.

In the UK, soil-water content can remain constant at field capacity for several months during winter when most leaching occurs. This sort of local knowledge can be exploited in the design of empirical models. Such models, for example CALF (11) use minimum input data and useful simulations can be achieved from such few data as a sorption coefficient, a half life of degradation at a known temperature and soil-water content, the soil-water content at field capacity and soil bulk density. Widely available weather data of only rainfall and maximum and minimum air temperatures drive the model. The data are easily available to pesticide chemists and the results of simulations are usually as good as those from mechanistic models (8) (Figure 1). Empirical models are sometimes criticised for not being based on established scientific laws, but the most widely used leaching model, PRZM (2), also uses an empirical method to calculate water movement.

Cleverly designed models do not just consist of the scientific laws but use the experience of their designers to set the boundary conditions over which the laws work well and which will be required during the operation of the model. Both mechanistic and empirical models have been widely used for environmental risk assessment and have been incorporated into regulatory protocols. These model e referred to below as equilibrium models b they assume that sorption is fully equilibrated and that water completely mixes among pores of different sizes.

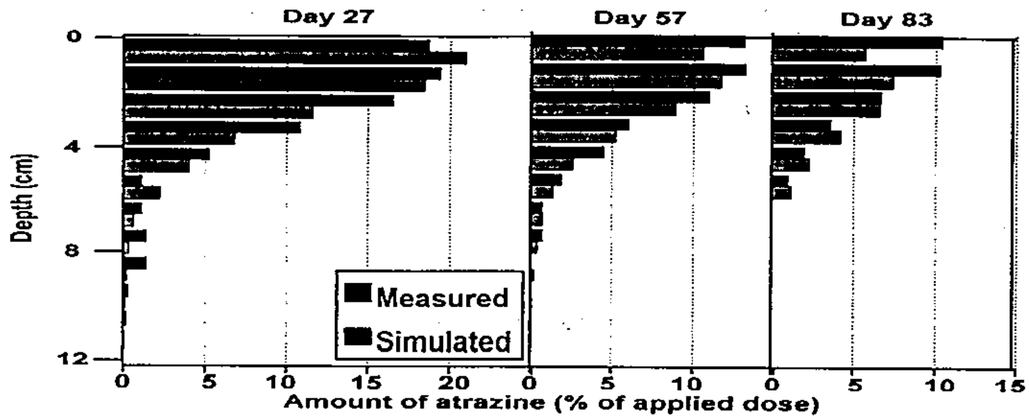


Figure 1. Distributions of atrazine in the field for a fallow sandy loam soil at different times after application. Simulations were done using the model CALF (11).

## PREFERENTIAL FLOW MODELS

Equilibrium models usefully predict the distribution of the majority of pesticide (usually more than 99% of the applied dose) that remains in the top layers of soil. Recently concern has moved to the small proportion of the applied dose of pesticide that leaches deeply to groundwaters and drains. In Europe the concern is to conform to an EU drinking water ruling that states that no single pesticide should exceed a concentration of 0.1 µg/L in tap water. The trace concentrations of pesticides that reach ground and surface waters frequently do so by the mechanism of preferential flow (sometimes called macropore or bypass flow).

In structured soils, and even in some light-textured soils, water can move rapidly down larger pores carrying dissolved pesticide. During such rapid flow, the pesticide does not have time to reach sorption equilibrium with soil particles nor to diffuse into smaller pores. Hence pesticides that might otherwise be sorbed quite strongly in the topsoil can penetrate deeply to drainage waters. More than 90% of UK soils probably require a specifically designed preferential flow model for the simulation of trace concentrations of pesticides that leach deeply. Two examples of preferential flow models are MACRO (4) and PLM (3). However, it is uncertain whether current models can be used predictively because the results of the simulations of preferential flow for pesticides are so extremely sensitive to the macroporous properties of the soil. Trace concentrations in leachate can be accurately mimicked by preferential flow models after they have been calibrated for the soil under consideration (Figure 2). Nevertheless, it is probable that in the medium-term future we will learn how to use preferential flow models predictively.

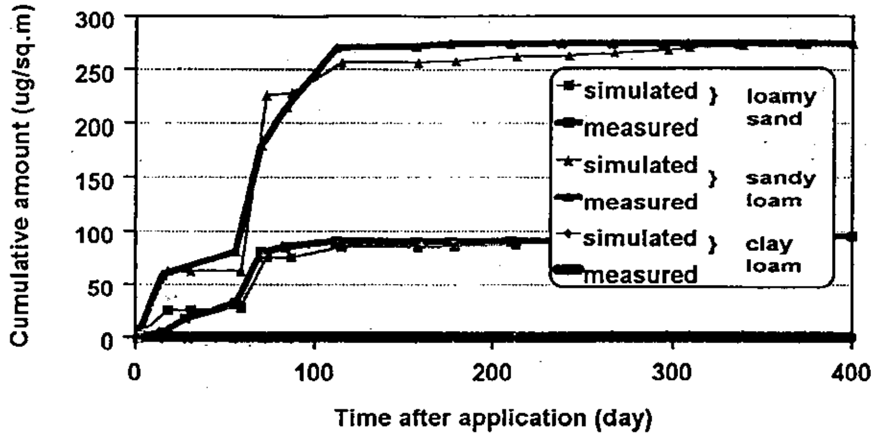


Figure 2. Measured and simulated concentrations of a pesticide in lysimeter (1 m depth) leachates for three types of soils.

Databases of input data are integrated with model softwares (5) (eg in MACRO_DB). These databases will provide the physical properties of soils that can be otherwise difficult to obtain. The soil properties that describe the macroporous nature of structured soils are nearly always obtained from databases provided with preferential-flow models.

It is concluded that, except for the minority of soils that do not exhibit preferential flow, it is not possible to use leaching models to assess the risk of contamination of ground and surface waters because equilibrium models do not simulate preferential flow and preferential-flow models are not yet sufficiently developed to be predictive.

## A KNOWLEDGE-BASED APPROACH

From the account given above, it might seem that current lack of knowledge prevents scientific risk assessments from being made. In fact, we often have a great deal of practical knowledge from the results of laboratory, lysimeter, field plot and monitoring studies on a wide range of pesticides used in arable agriculture in a number of regions of the world. In North West Europe for moderately polar, moderately persistent herbicides such as isoproturon and atrazine, typically up to 0.1% of the applied dose can leach through soils to drainage water. For more lipophilic and hence more strongly sorbed herbicides and insecticides, such as trifluralin and cypermethrin, up to 0.001% of the applied dose might leach. For cypermethrin the rate of application is so low that any that is leached is unlikely to be detected. The proportion of compound leached is somewhat, but not completely, independent of the physical properties of both the compound and the soil under the conditions of preferential flow. An empirical routine was developed to calculate the proportion of compound leached through a lysimeter during one year of average UK weather conditions from a knowledge of sorption coefficient, half-life and rate of application. The routine is included in a Windows-based decision-support system called "Physicochemical Evaluation - The Environment" (9). The routine gives results that are consistent with experimental results from lysimeters and from field monitoring studies. Further study of experimental data will be required before this method can be calibrated for other climates.

## TROPICAL AND SUB-TROPICAL CLIMATES

The majority of models that simulate leaching and degradation of pesticides in soils were developed and validated in Northern Europe and the USA. Is it necessary to develop different approaches for modelling in tropical soils and climates? Rates of degradation of pesticides increase with temperature and soil-water content and such dependencies are included in present models (12). In the tropics, temperatures are higher than those for which the models were developed, but the existing relationships are expected to hold, although further testing is clearly necessary. If changes were required, it would not be difficult to modify temperature relationships to improve their predictiveness for tropical conditions.

The intensity and duration of rainfall at certain times in the tropics is high and hence is expected to give rise to preferential flow. Preferential flow models are thus even more likely to be required for simulation of leaching in tropical conditions. None of these considerations implies a different approach for tropical conditions (7).

However, there is one distinct property of some tropical soils that is not prevalent in more northerly climates and that is the balance of electrostatic charge on the surfaces of soil particles can be positive. A large proportion of herbicides are acids, and their anions produced by dissociation will be attracted to any positively charged surfaces of soils (typically those high in iron sesquioxides). The acidic herbicides will be more strongly sorbed and hence less mobile than they would be in soils from northern climates which have a predominantly negative balance of charge. Present models (12) that predict sorption of ionisable compounds to soils need further development for those tropical soils that are positively charged.

## ACKNOWLEDGEMENTS

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# QUARANTINE POLICY - MINIMISING NEW WEED PESTS

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*Summary:* In deciding to prevent the importation of a plant because of its potential as a "quarantine weed", contracting parties to the International Plant Protection Convention (IPPC) or members of the World Trade Organisation are obliged to follow a decision-making policy consistent with IPPC standards. This means that only plants which do not occur in the importing country, or occur only in limited distribution and are under official control, and which are assessed to be economically important, can be prohibited from importation. Issues relating to use of the quarantine pest definition and the need for additional standards are discussed.

*Keywords*: quarantine risk assessment

## INTRODUCTION

A holistic approach to integrated weed management must include a quarantine component as minimising the number of economic weeds in any production system is an important strategy in maximising effective weed control options. The focus of this paper is on the disciplines a national government must comply with in firstly determining its quarantine weeds and secondly in establishing quarantine measures against them. The International Plant Protection Convention (IPPC), which was deposited with the Food and Agriculture Organization (FAO) in 1951, deals specifically with plant health and quarantine issues. Over the last decade the IPPC's contracting parties have developed standards which outline various plant quarantine methodologies. The overriding imperative for compliance with these standards, however, comes from the agreements which establish the World Trade Organisation (WTO). One of these agreements, the Agreement on the Application of Sanitary and Phytosanitary Measures (the SPS agreement), includes measures to protect human, animal or plant life or health from risks arising from quarantine pests (13). The SPS agreement recognises standards developed under the IPPC. A "*quarantine pest*" is defined in IPPC standards as "*A pest of potential economic importance to the area endangered thereby and not yet present there or present but not widely distributed and being officially controlled*" (4). This definition can be broken into three criteria; economic, geographic and regulatory. Historically it has been understood that the term "pests" includes "weeds" and in recent international consultations to consider amendments to the IPPC it was agreed to make this understanding explicit (IPPC Secretariat, unpublished). Assessment against all three criteria must be made before the government body authorised to discharge a country's obligations under the IPPC ie the National Plant Protection Organisation (NPPO) can consider classifying an organism as a quarantine pest. Phillips and Chandrashekar (12) discussed scientific issues from the previous quarantine pest definition, however, that was with respect to pathogens and additional discussion with respect to weeds is warranted.

## DISCUSSION

*International Treaties:* There are 131 member countries of the WTO and a further 29 are being considered for accession (WTO World Wide Web page, 1997.). The SPS agreement came into force for developed countries with the formation of the WTO on 1 January 1995 and for developing countries on 1 January 1997. Least developed nations have a further three years before they are obliged to adopt the disciplines required by the SPS agreement. These nations have the opportunity to take advantage of this time to input into the standard setting processes, so that their particular circumstances are accounted for in advance of compliance. Development of the SPS agreement was motivated by a concern that unless clear rules were made in the area of phytosanitary (ie plant quarantine) measures, gains achieved in the negotiations concerning reduction or removal of tariff barriers to agricultural trade would be eroded by the imposition of additional and unjustified restrictions in the form of sanitary and phytosanitary barriers.

The SPS agreement imposes disciplines on the actions taken by national governments to prevent the importation of plants which they consider are weeds. It provides for dispute settlement and the imposition of penalties where members disagree on quarantine restrictions. Such restrictions must: be applied only to the extent necessary to protect life or health; be based on scientific principles; not arbitrarily discriminate between members of the WTO; be based on relevant international standards; and not be more trade restrictive than is necessary to achieve the appropriate level of protection. In addition, they must be made and maintained in a transparent manner ie clearly stated and open to scrutiny by WTO members, if requested. The WTO recognises that the IPPC Secretariat is the body best placed to coordinate phytosanitary standards development and the secretariat has already published several relevant standards and others are under active development.

*Quarantine weed:* The IPPC pest risk analysis (PRA) standard (2) provides a description of the process NPPOs are to use to determine which organisms should be considered quarantinable. A flow chart (Fig. 1), extracted from this standard, demonstrates the criteria used in determining whether an organism should be assessed as a potential quarantine pest. Although it addresses all pests, the focus of this standard is on the movement of pests via traded commodities. Its application to the assessment of potential pests which are commodities requires some additional interpretation. In the assessment of a plant to determine if it is quarantine pest (ie quarantine weed) in their own right (eg seed which is for sowing rather than its contaminants), this is particularly so against the regulatory and geographic criteria.

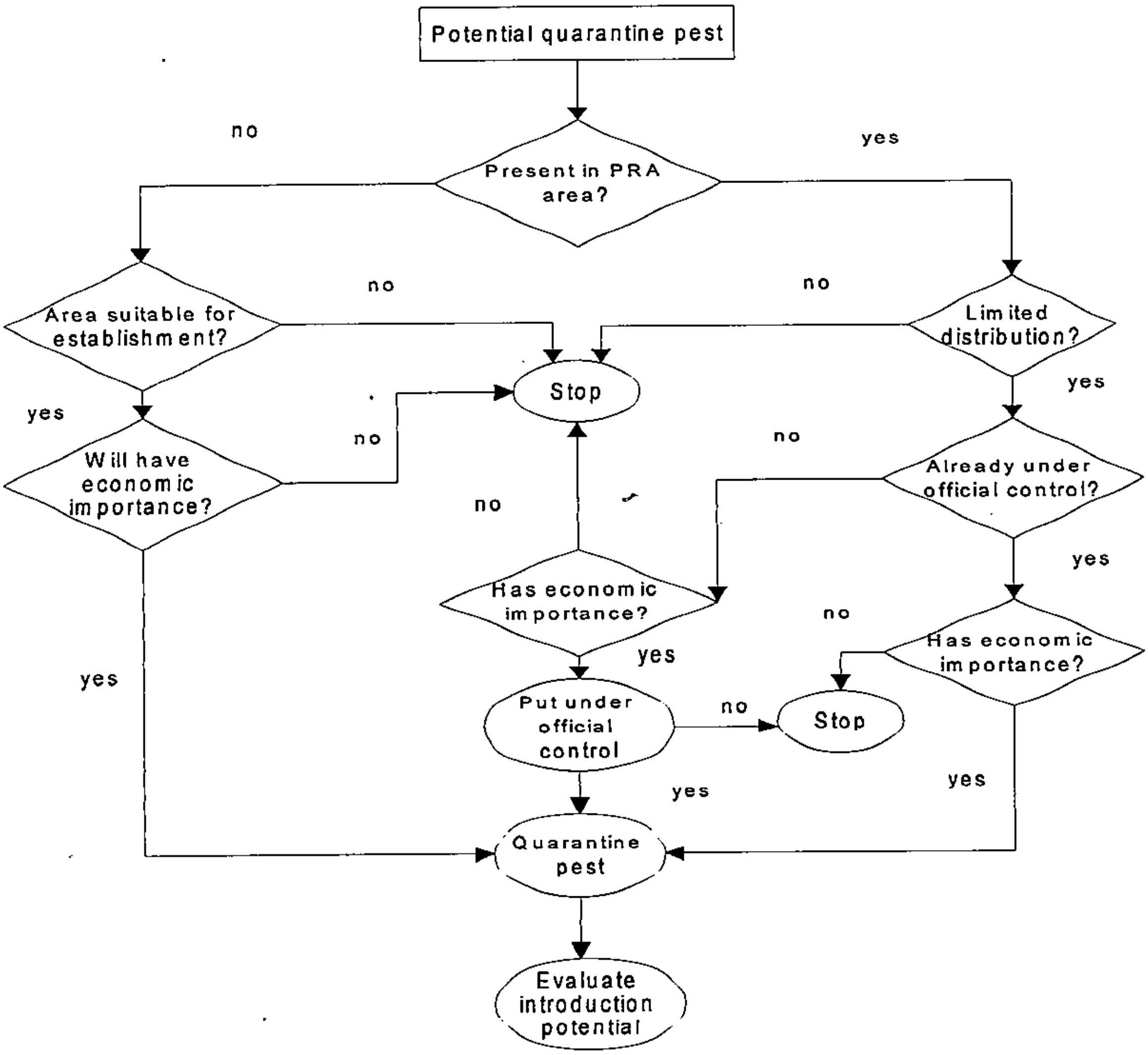


Figure 1 Pest risk analysis, stage 2: Assessment. (2)

A logical starting point in most new pest risk analyses is with the regulatory and geographic criteria. The first significant question is presence or absence in the importing country or a quarantine area within that country. If the plant is not present it can be considered a potential quarantine weed. If the plant is already present in the country then it can only be considered a potential quarantine weed if it is of limited distribution and under official control. For example, there is no justification for classifying a plant a quarantine weed if the same taxon is already at the extent of its natural range in a country because this poses no risk of spread. An exception would be where the new entry is clearly different in weed risk status from the plants already occurring. An example of this would be the importation of a fertile member of a species where only sterile clones currently occur in the importing country. If the species is found in a limited range, ie there are still significant areas within the country susceptible to infestation, but it is not under official control, then it cannot be prevented entry on quarantine grounds. In these circumstances, official control measures must be put in place to justify any quarantine. The next step is to assess the potential economic importance of the plant. If it fulfils all these criteria, the plant's introduction potential needs to be assessed, where introduction means "*Entry of a pest resulting in its establishment*" (4). In the context of a weed, established (ie "*a population which can perpetuate itself for the foreseeable future*") (4) can be taken to mean naturalised (ie "*an invading plant that has become established and has reproduced for several generations in the wild.*") (6). Therefore, when it is known that propagules of a species will enter the country (eg when the plant proposed for importation is being assessed) its introduction potential cannot be assumed to be certain as it may not have the ability to naturalise, even with human assistance.

If a plant is assessed as a quarantine weed with the potential for introduction, risk management strategies are then developed to reduce the risks of introduction to a manageable level. Analysis of the pathway a quarantine weed may follow to arrive in a country is required to determine the most effective point/s to apply risk management strategies. Application at the most effective point will ensure that phytosanitary measures will have minimal impact as required by the IPPC and the WTO (1, 13).

Risk management can be applied either in the country of export or the country of import or both. Pre-export strategies include area freedom and the IPPC Secretariat has developed a standard codifying this concept (3). Phytosanitary certification by the NPPO in the exporting country on the basis of inspection of a sample of a commodity is also a commonly practiced strategy. Post entry strategies are for example stipulation of end use of a commodity which will devitalise any weed seeds, such as milling. Clearly, if we are considering a plant which is to be propagated if importation is permitted, the only strategies which are applicable are those which restrict the plant's distribution once it has entered a country, eg confinement in a research facility.

*Geographic criterion:* The term "present" is not defined by FAO. If prevention of establishment is the goal of quarantine measures, then "establishment" could be considered the benchmark for whether or not a pest is present. However, if this debate is viewed from a risk management perspective, a non-naturalised plant population is a source of propagating material and therefore a source of some risk. Defining the species which are present in a country, therefore, can be problematic.

In Australia, for example, European settlement has resulted in an extensive introduction of non-indigenous plants, of which in excess of two thousand species have become naturalised (6). As records of individual importations have not been kept it may be impossible to know definitively all the plants that occur in Australia, despite its advantage of being an island nation. For nations with land borders the potential for natural spread of plants adds another dimension to the problem of developing an inventory. Surveys of naturalised plants; inventories from public gardens and gene banks; and commercial sales catalogues can identify a large proportion of a country's total flora. It is uncertain if these sources account for all species and the question is, "is such an inventory sufficient for quarantine purposes?" It can be argued that if a plant is a weed then it will be recorded in flora surveys as naturalised and will therefore be included in the above sources. Assuming regular surveys are conducted, if a species is growing in a country, but is not recorded, it may be safe to assume that it poses a minimal risk. This view is supported by examples cited by Humphries *et al.*, (6), which indicate that it may take up to one hundred years before an introduced plant becomes a weed problem. If we accept this position, then there is little risk from the unrecorded internal population, and the use of a quarantine measure to minimise risks from external sources may be justified.

The next question is, "of those plants that occur, which ones are not widely distributed?" It is accepted that a pest which has not reached its ecological range is considered "*not widely distributed*" (2). Computer models such as CLIMEX, Bioclim and Climate are useful tools for the prediction of a pest's potential ecological range (5, 10). Surveys may be required to measure the actual distribution of a weed so that a comparison with its predicted potential in order to determine if the weed is or is not widely distributed.

*Regulatory criterion:* The term "official control" can be derived from its constituent terms as the suppression, containment or eradication of pest population, established, authorised or performed by NPPO (4). The most liberal case is suppression which is defined as "*The application of phytosanitary measures in an infested area to reduce pest populations and thereby to limit spread*". Measures such as biological control could be considered here, if effective and authorised by the NPPO. The word authorised implies some legal authority and this is commonly considered to be the authority invested in government officials. The intention appears to be that the NPPO must be satisfied that the programme is actually controlling the pest population. In this context, effectiveness of a control programme relates to the rate of increase in the area infested by the weed. Determining whether the rate of spread is actually limited by the control measure is a question of prediction and therefore open to debate. Panetta and Scanlan (8) showed that humans contributed to nearly 90% of all exotic weed dispersal and they were the sole factor in 21% of cases. This indicates that in the majority of cases the effectiveness of control programmes in limiting the spread of a species will be improved if it has legislated backing which can prevent humans from dispersing propagating material. Such legislative action is also an indicator of the seriousness with which the weed is viewed by the county which is seeking to justify a quarantine measure used to protect against the particular species.

Another difficult situation is where a few specimens of a species occur in a public place. Regulations which prevent human removal of plant material from public places such as botanical and zoological gardens cannot prima facie be considered "official control". Some biological assessment of spread potential from the known sites must be undertaken before considering a species officially controlled. Similarly species which already exist in a gene bank located in the country may require specific legislation which prevents unrestricted release before they could be considered for quarantine weed status.

*Economic importance criterion:* A large number of the exotic species which have established in Australia and become major pests were not considered serious overseas (A Catley, pers. comm., 1997). Paterson's curse is a serious weed throughout much of Australia, however, at worst it is a minor weed wherever else it occurs in the world (Parsons and Cuthbertson, 1992). Predicting economic importance is therefore critical in establishing effective quarantine measures. There is an overlap here with the assessment of establishment potential and the extent of distribution discussed above, as a weed must establish and spread if it is to have an economic impact. A supplementary standard to the pest risk analysis standard, dealing with economic impact assessment is currently in preparation (2).

In Australia, assessments of weed potential of proposed plant imports are currently carried out by AQIS using the WRA system (10). This is a scoring system which takes into account available information on a plant's biology, ecology and biogeography as well as any weed and cultivation history it or its near relatives have. The factors which most strongly influence the WRA to assess a plant to be a weed are its history as a weed in other countries, near relatives' weed histories or an aquatic growth habit. A long history of domestic cultivation strongly influences the assessment in the other direction. The output of the system is a score which is a prediction of the potential weed status in Australia.

A large proportion of the plants proposed for importation into Australia are for ornamental end uses (eg horticultural plants for private or public gardens or parks) and often very little information is accessible. The WRA system copes with this information gap by breaking its assessment into a large number of questions of which the assessor only has to answer a minimum number. In circumstances where the assessor considers that it is not appropriate to apply the WRA model, alternative methods, including consultation with scientific experts, are considered.

*Conclusion:* Effective quarantine measures can help prevent integrated weed control strategies from being undermined by new weed problems. International agreements impose disciplines on NPPOs to ensure that any quarantine barriers they establish are justified and have minimal impact on international trade. A basic framework exists to guide the process and methodology used to carry out plant quarantine weed risk assessment. However, the details in a number of areas could be more clearly specified and it may now be beneficial to develop a supplementary standard to support the pest risk analysis standard (2) to deal with weed risk assessment.

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# Keyword Index